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GB 2257184 A US 4817712 A  
US 3578081 A

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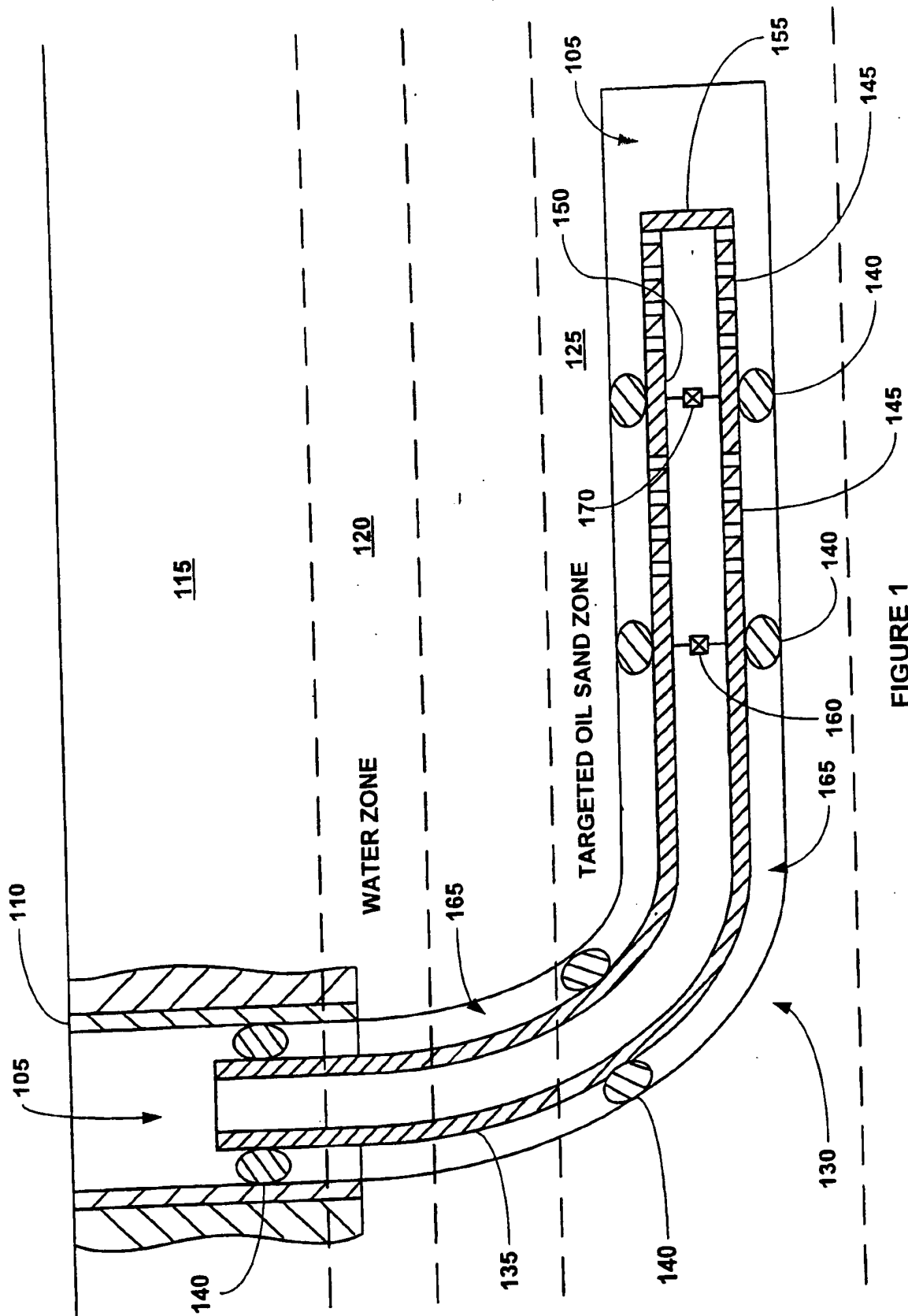


FIGURE 1

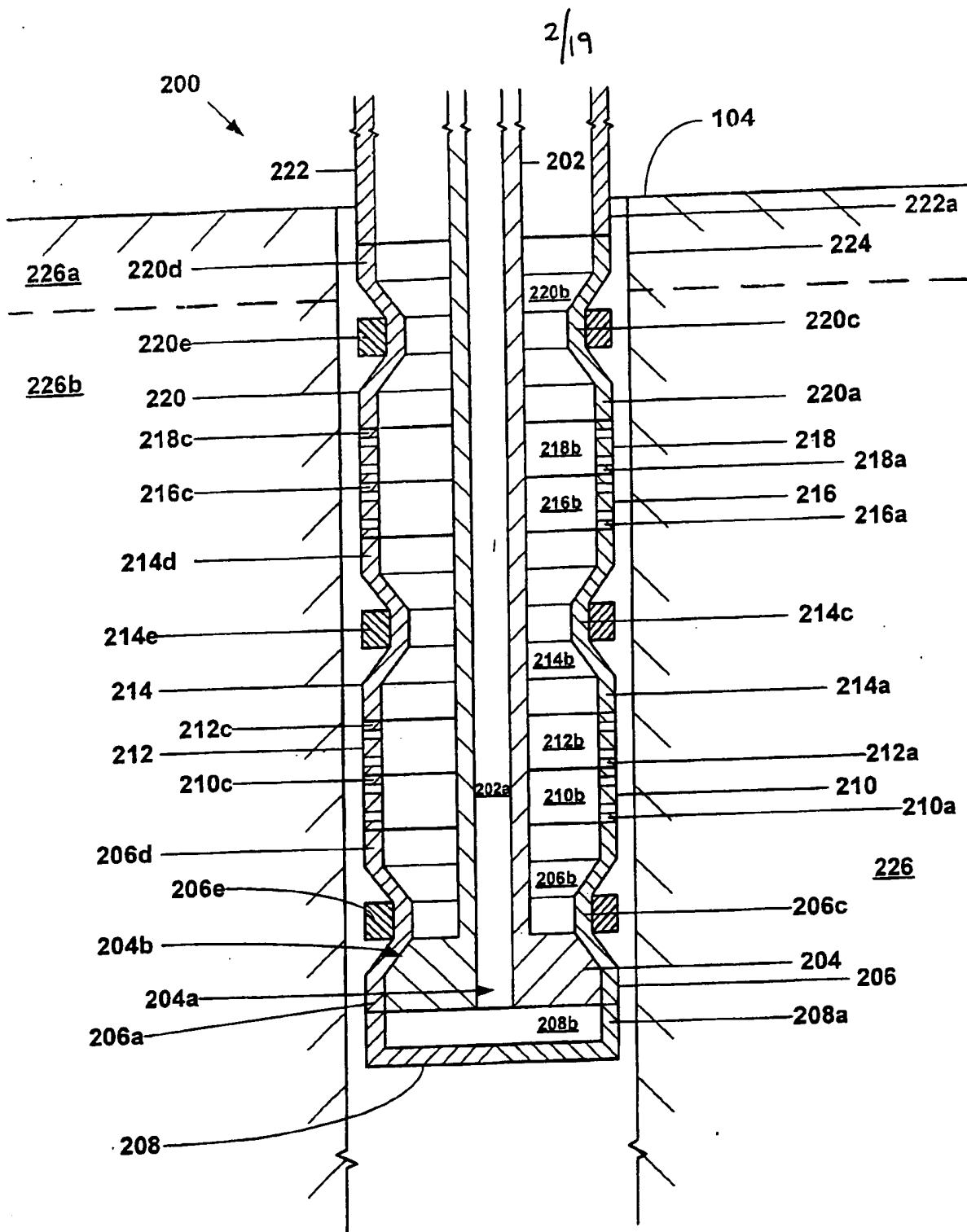


Fig. 2a

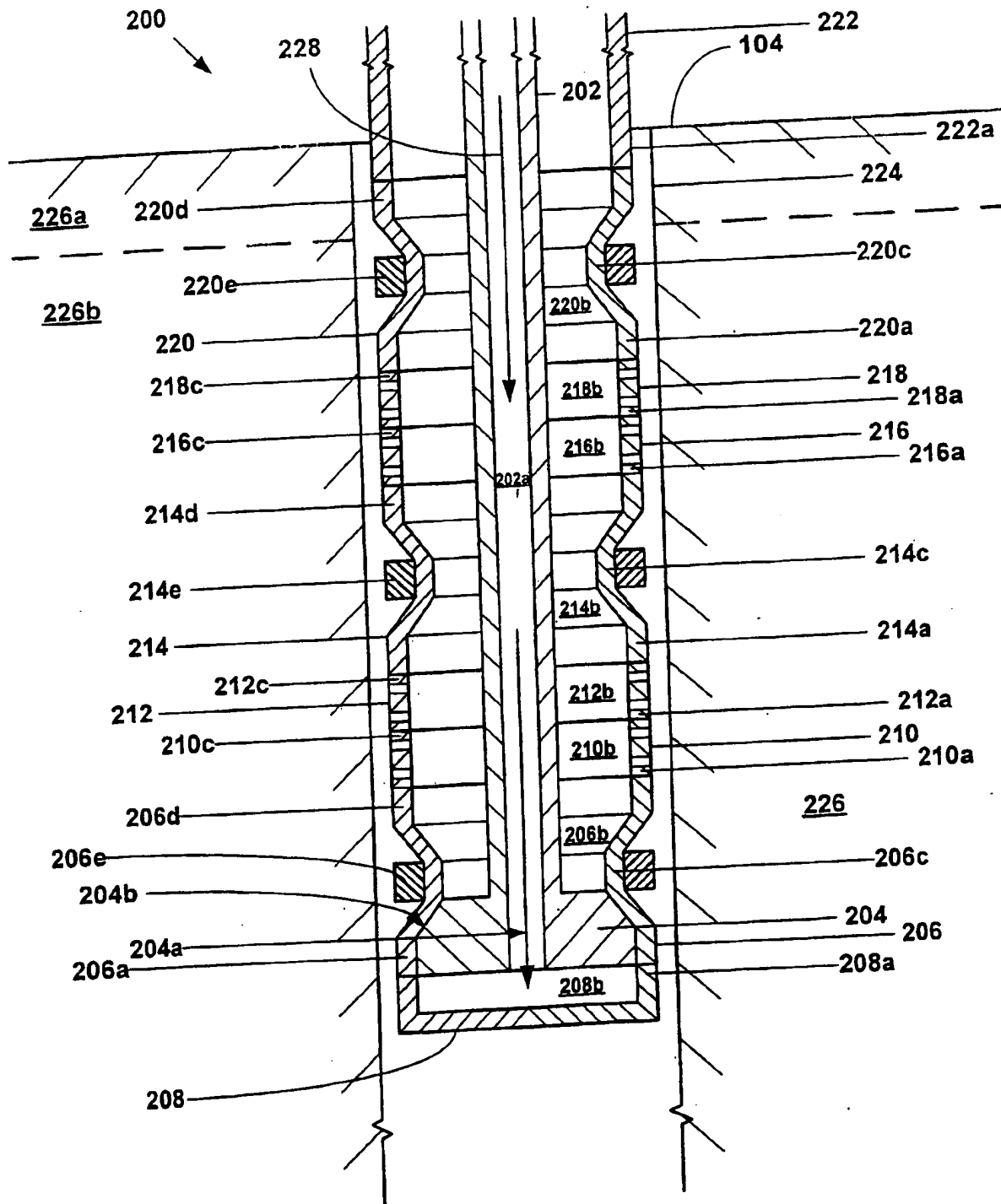


Fig. 2b

200

222

202

104

222a

224

226a

220d

226b

220e

220b

220c

220

218c

216c

214d

214

214e

204b

204a

212

102

212b

210b

206b

206

208

218b

216b

214b

214c

204

214a

218

216

216a

210

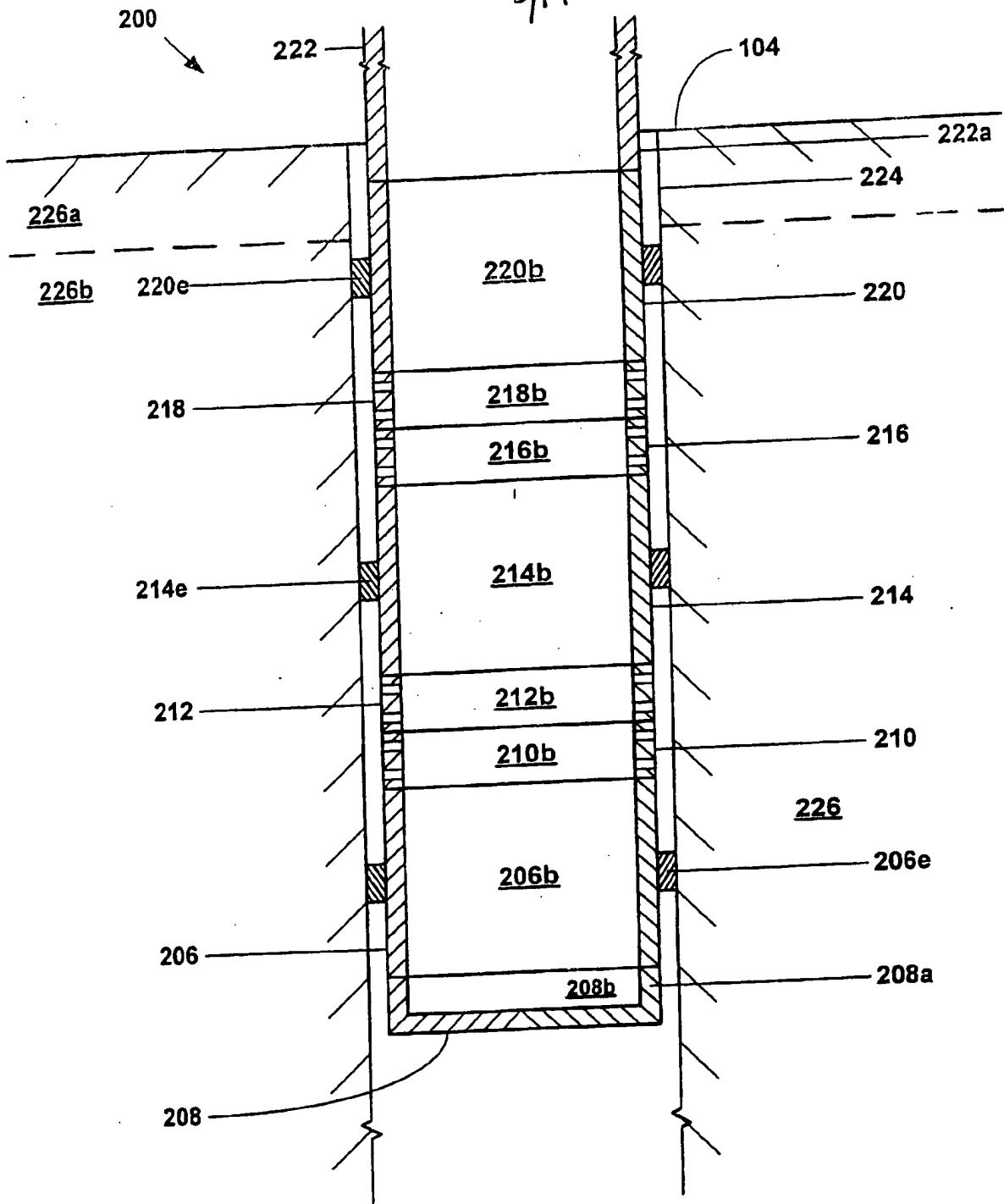
226

206e

208a

**Fig. 2c**

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**Fig. 2d**

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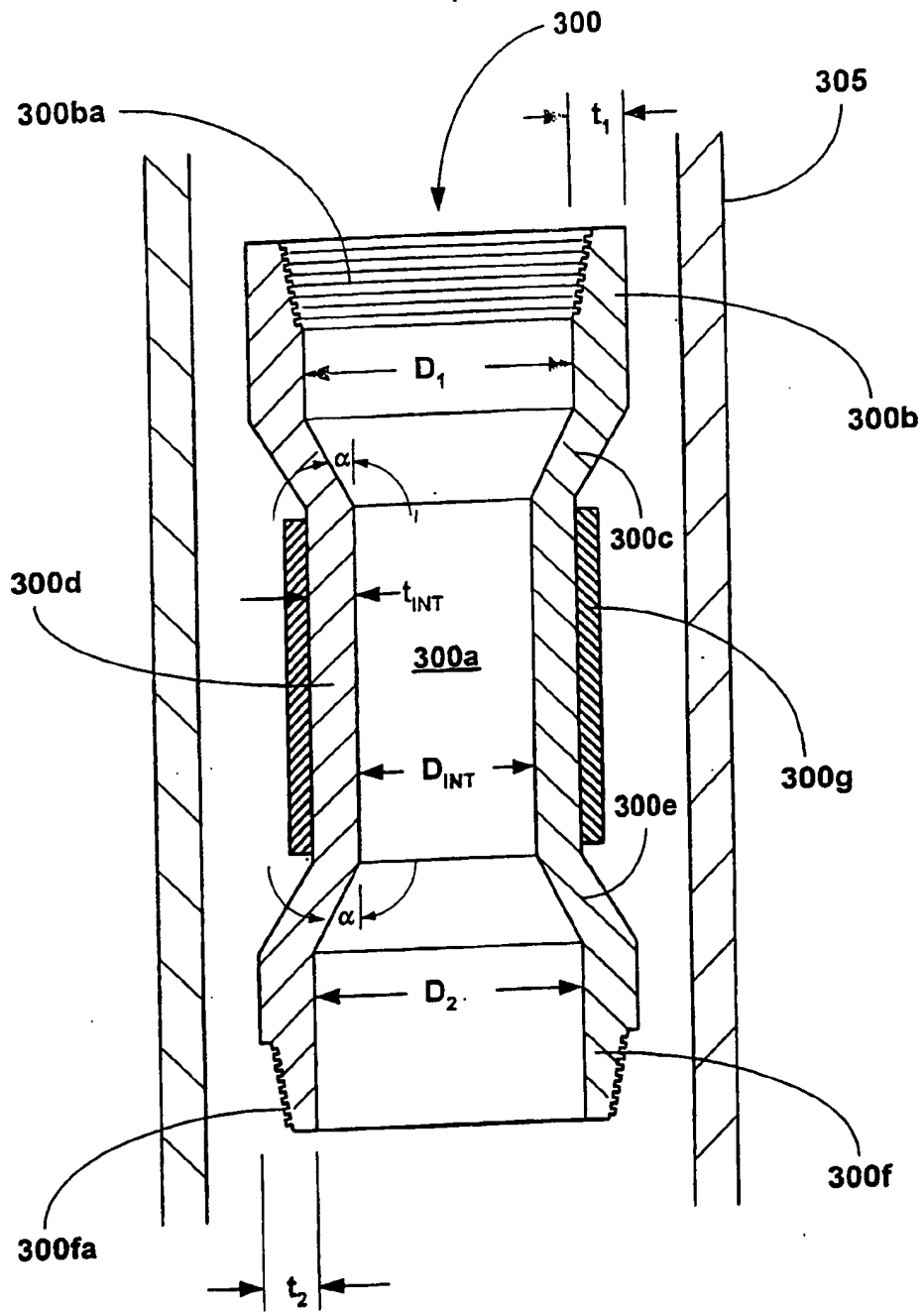


Fig. 3

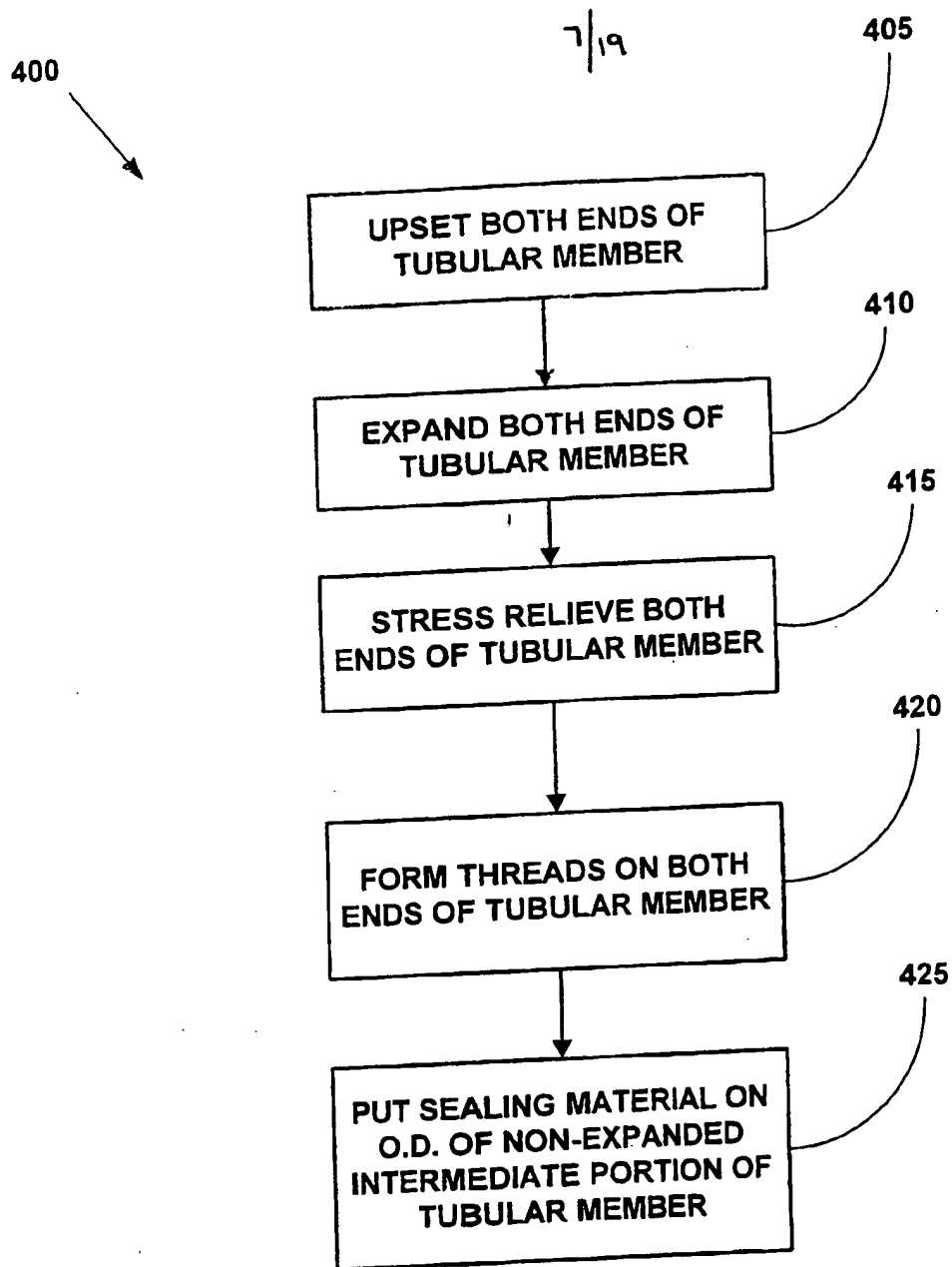


Fig. 4



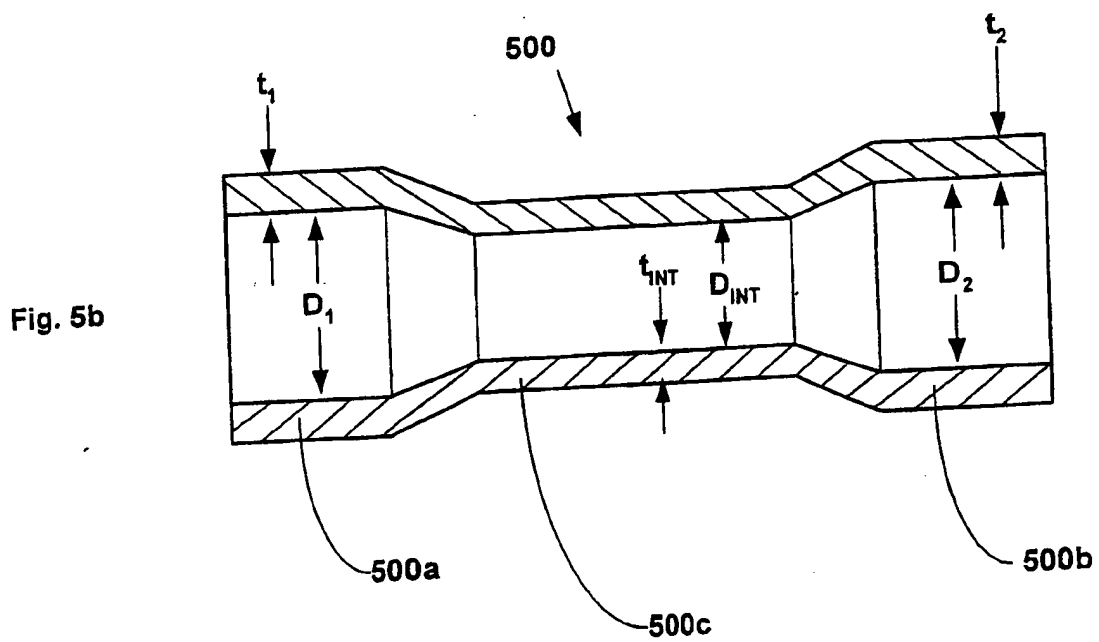
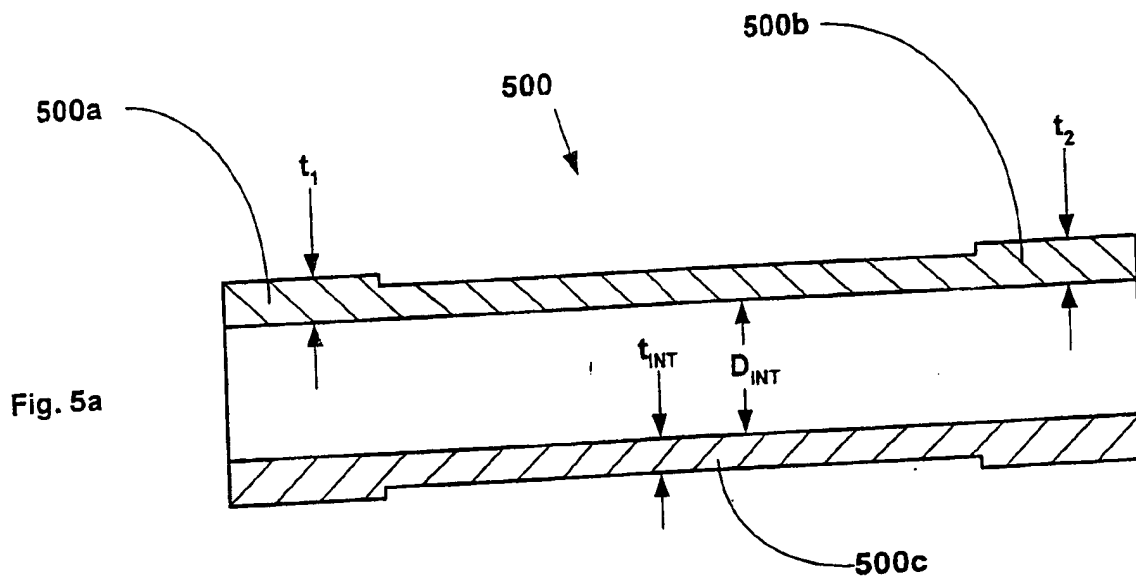


Fig. 5c

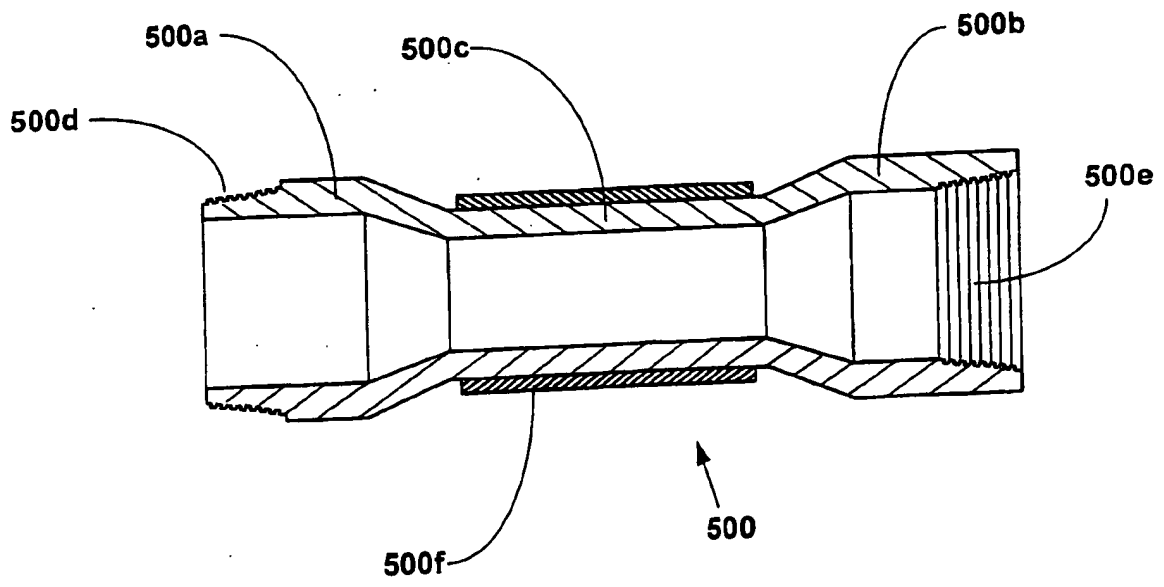
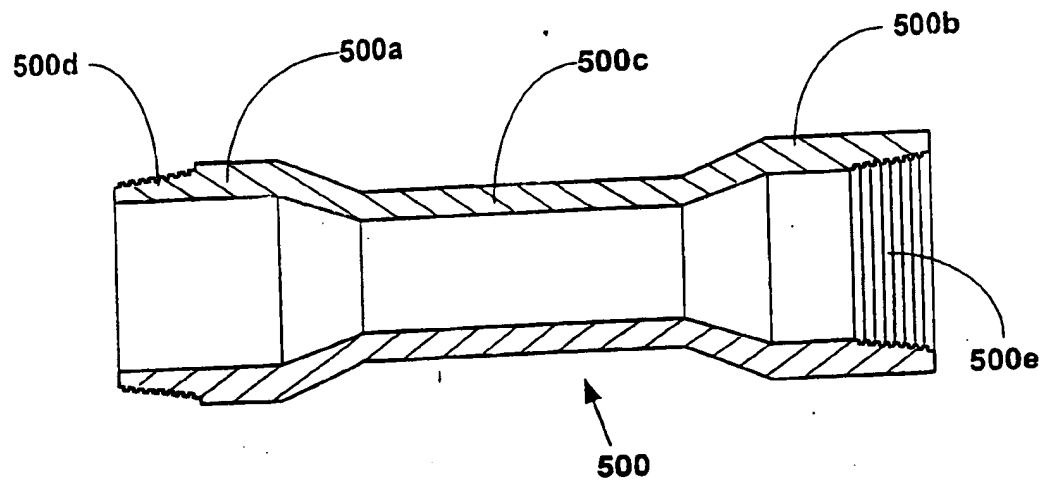


Fig. 5d

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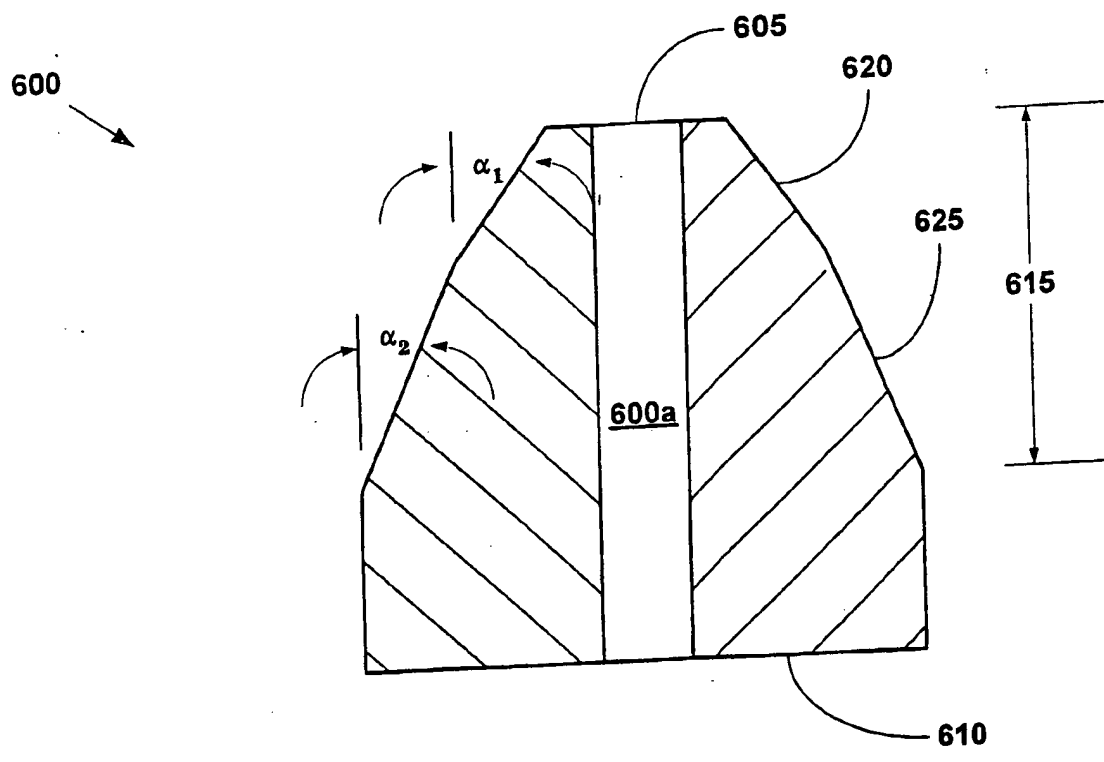
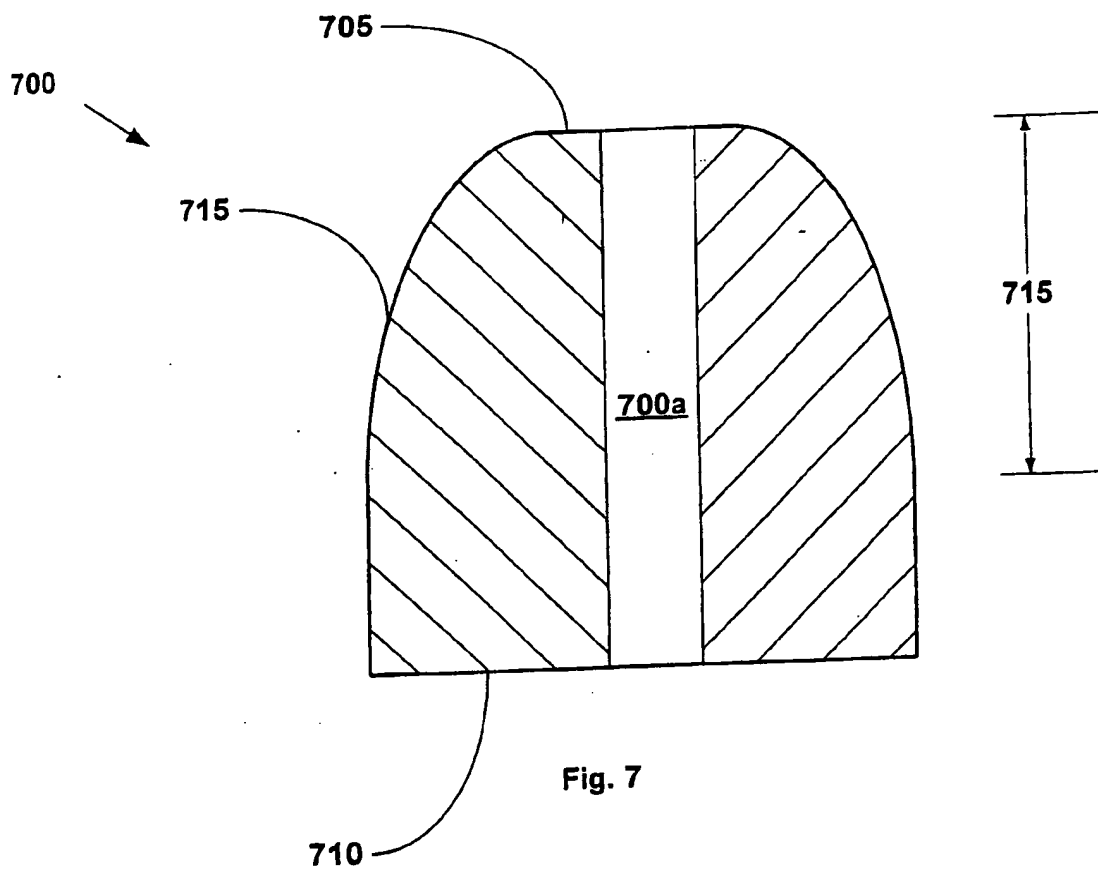


Fig. 6

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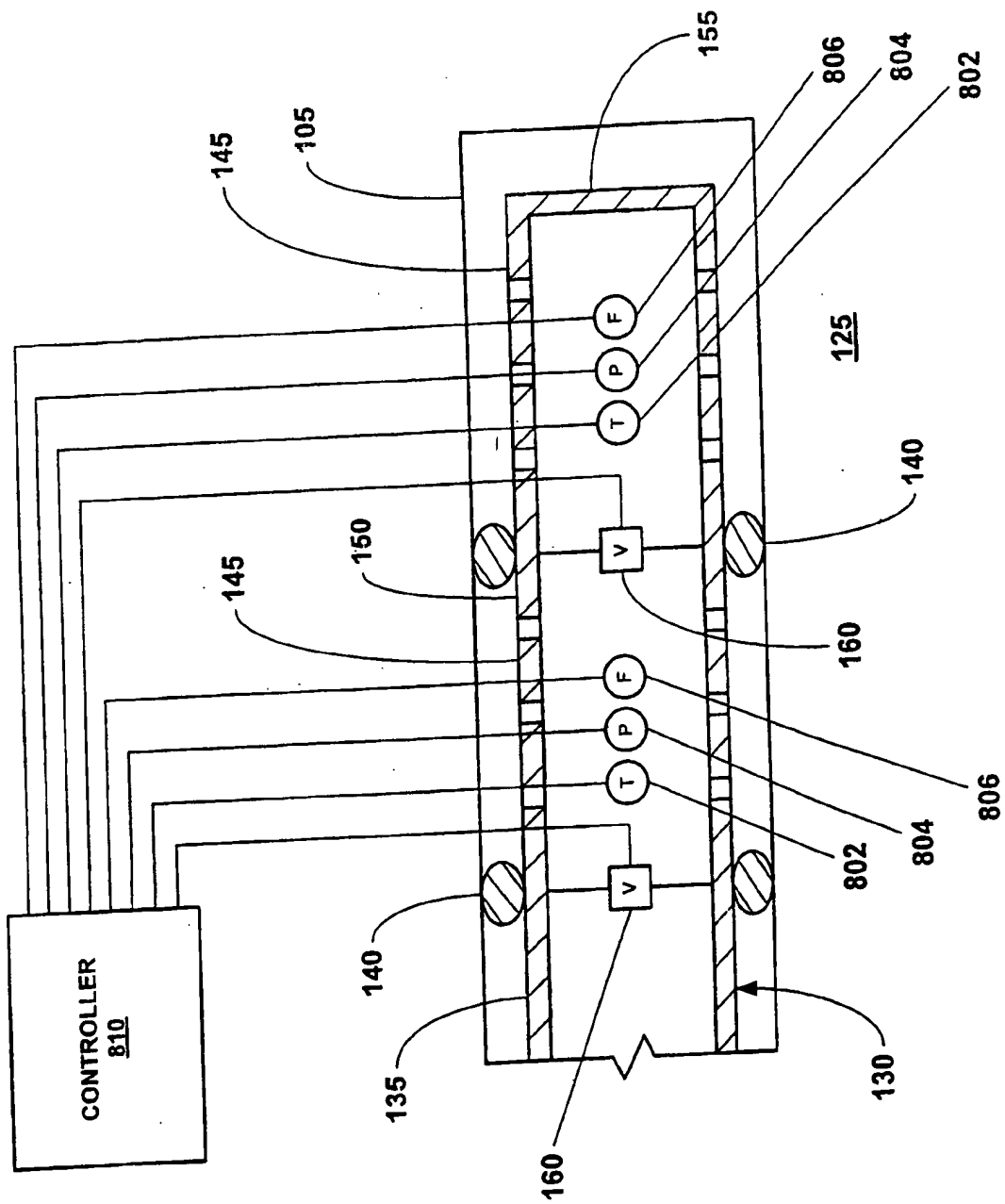


FIGURE 8

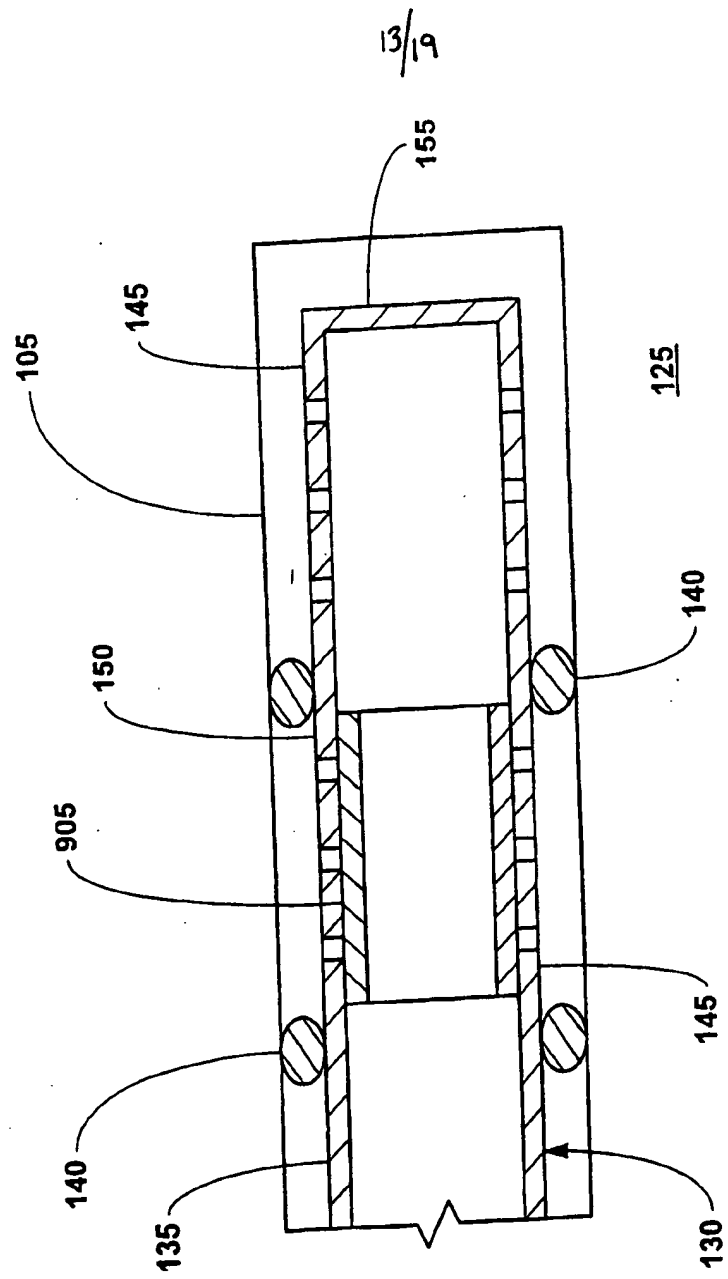


FIGURE 9

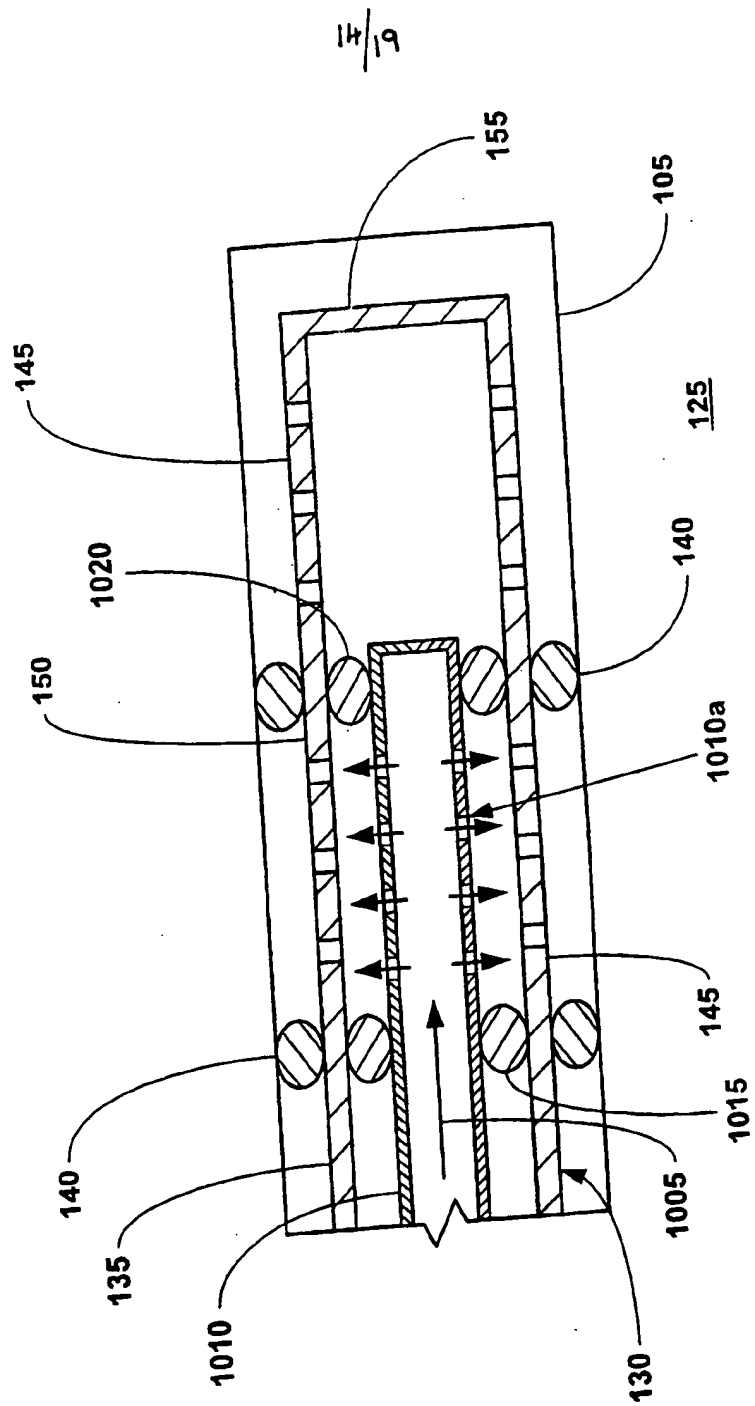


FIGURE 10

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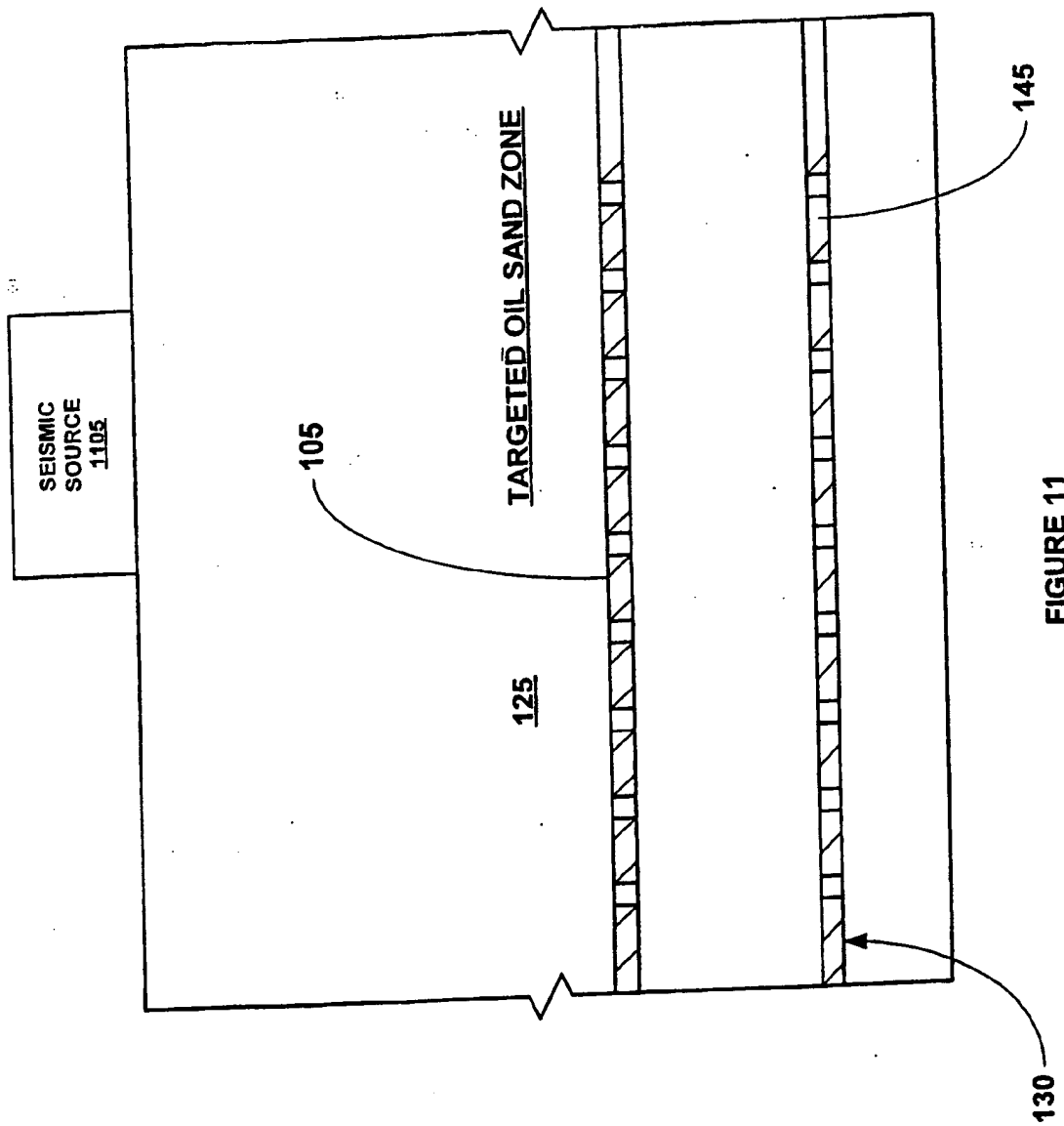
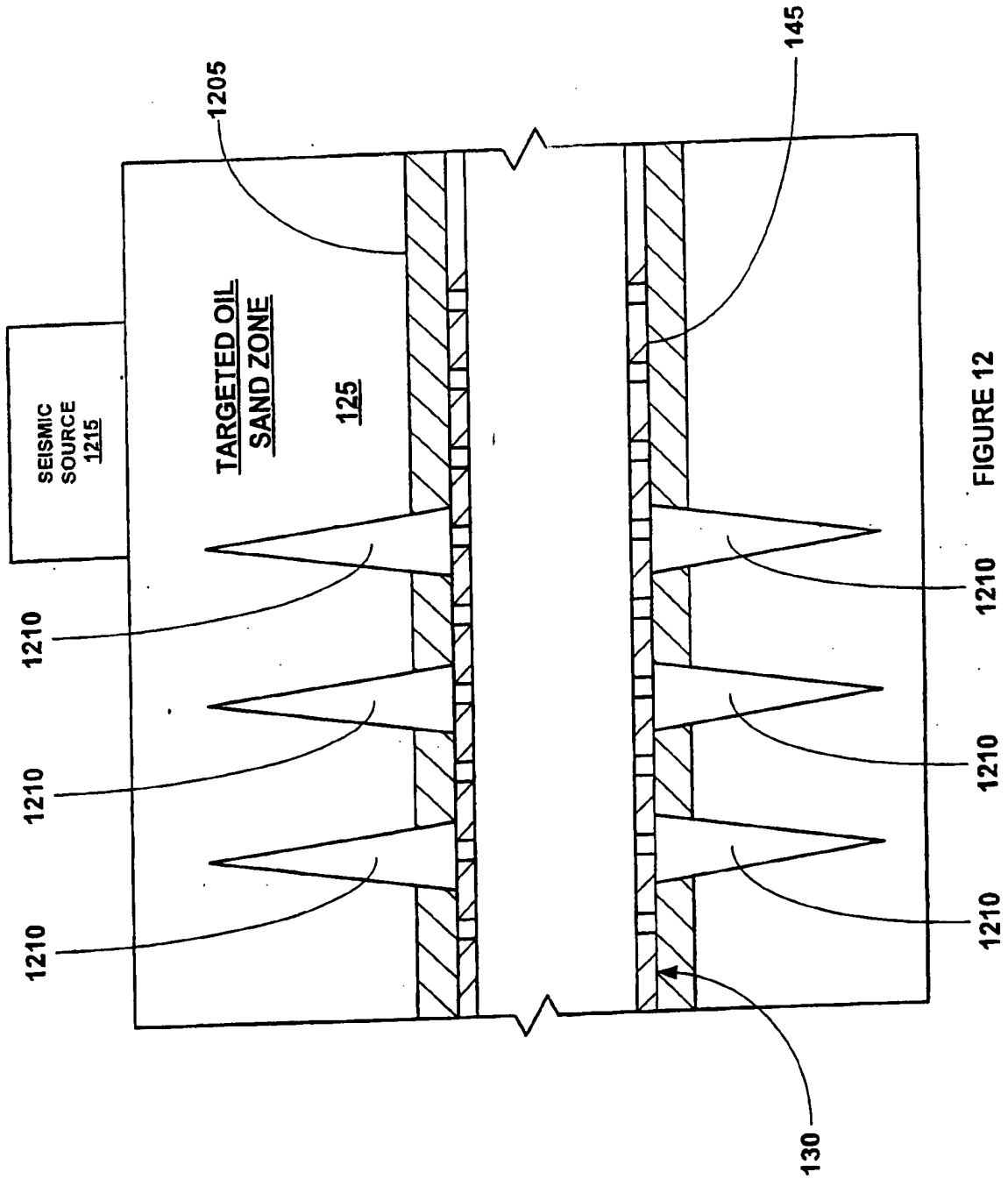


FIGURE 11



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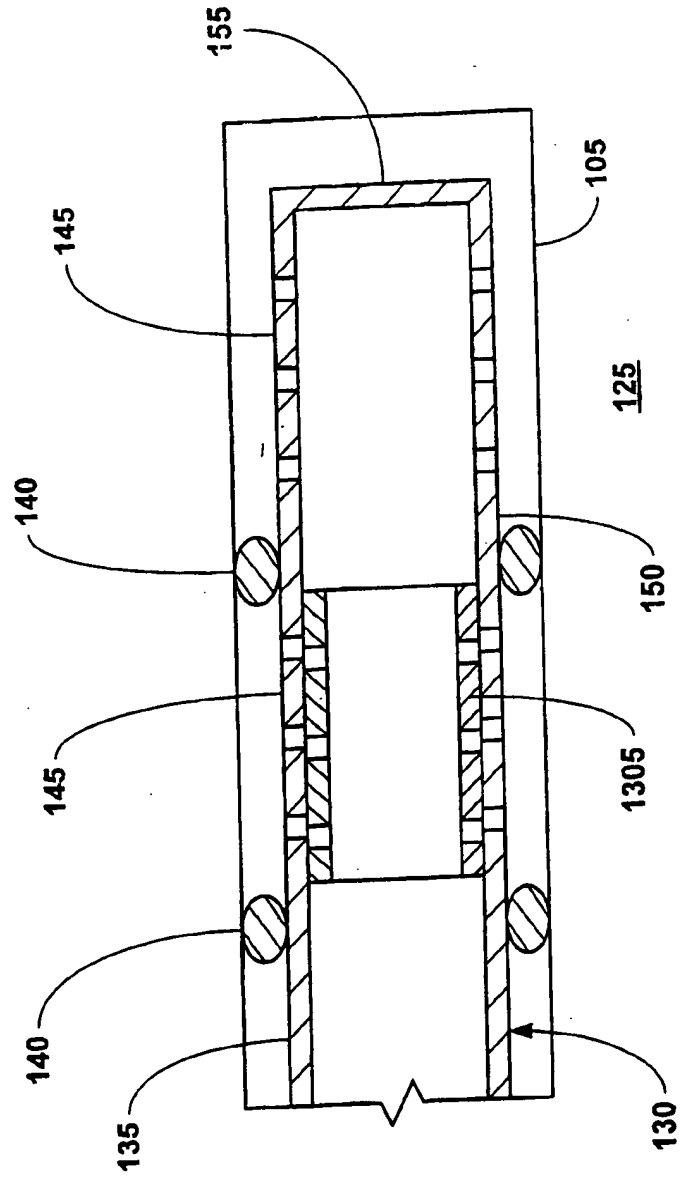


FIGURE 13

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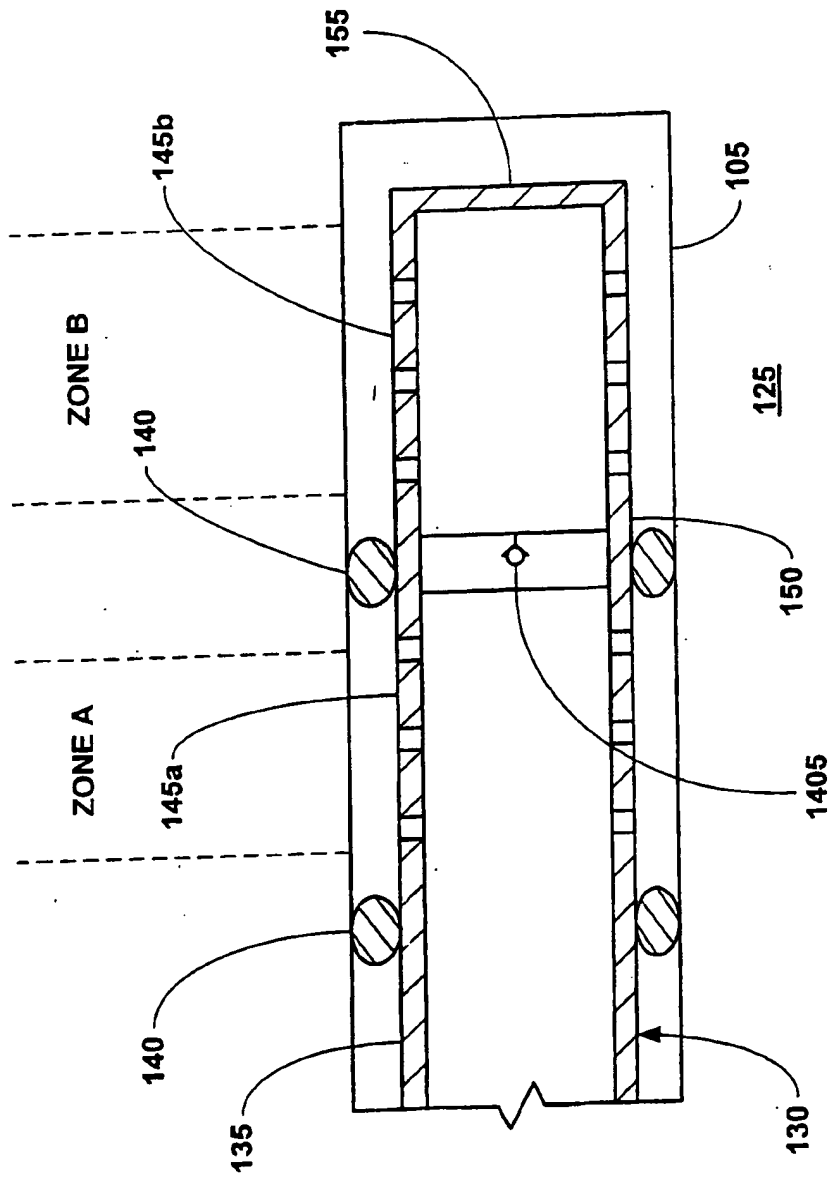


FIGURE 14

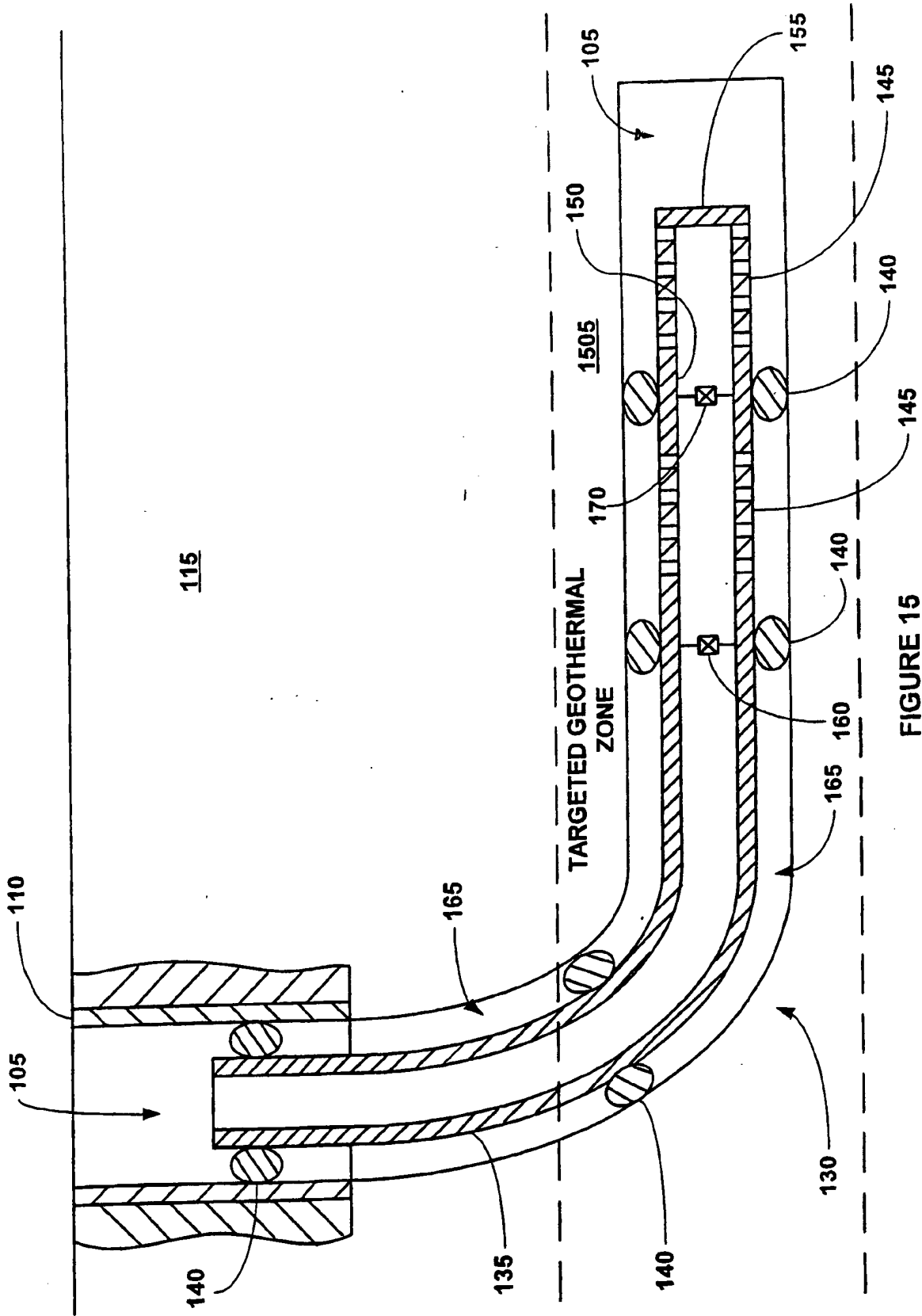


FIGURE 15

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## ISOLATION OF SUBTERRANEAN ZONES

### Background of the Invention

This invention relates generally to oil and gas exploration, and in particular to isolating certain subterranean zones to facilitate oil and gas exploration.

5 During oil exploration, a wellbore typically traverses a number of zones within a subterranean formation. Some of these subterranean zones will produce oil and gas, while others will not. Further, it is often necessary to isolate subterranean zones from one another in order to facilitate the exploration for and production of oil and gas. Existing methods for isolating subterranean production zones in order to facilitate the exploration for  
10 and production of oil and gas are complex and expensive.

The present invention is directed to overcoming one or more of the limitations of the existing processes for isolating subterranean zones during oil and gas exploration.

### Summary of the Invention

15 According to a first aspect of the present invention, there is provided an apparatus, comprising:  
a zonal isolation assembly positioned within a wellbore that traverses a subterranean formation and includes a perforated wellbore casing, comprising:  
one or more solid tubular members, each solid tubular member including one or more external seals;  
20 one or more perforated tubular members coupled to the solid tubular members;  
one or more flow control valves operably coupled to the perforated tubular members for controlling the flow of fluidic materials through the perforated tubular members;  
one or more temperature sensors located within a longitudinal flow passage of one or more of the perforated tubular members for monitoring the operating temperature within the  
25 perforated tubular members;  
one or more pressure sensors located within the longitudinal flow passage of one or more of the perforated tubular members for monitoring the operating pressure within the perforated tubular members;  
one or more flow sensors located within the longitudinal flow passage of one or more  
30 of the perforated tubular members for monitoring the operating flow rate within the perforated tubular members;  
a controller operably coupled to the flow control valves, the temperature sensors, the pressure sensors, and the flow sensors for monitoring the temperature, pressure and flow sensors and controlling the operation of the flow control valves; and  
35 a shoe coupled to the zonal isolation assembly;

wherein at least one of the solid tubular members and the perforated tubular members are formed by a radial expansion process performed within the wellbore; and

wherein at least one of the perforated tubular members are radially expanded into intimate contact with the perforated wellbore casing.

5        Preferably, the perforated tubular members that are radially expanded into intimate contact with the perforated casing compress the subterranean formation.

According to another aspect of the present invention, there is provided a method of isolating a first subterranean zone from a second subterranean zone in a wellbore that includes a perforated casing that traverses the second subterranean zone,

10        comprising:

positioning one or more solid tubulars within the wellbore, the solid tubulars traversing the first subterranean zone;

positioning one or more perforated tubulars within the wellbore each including one or more radial passages, the perforated tubulars traversing the second  
15        subterranean zone;

radially expanding at least one of the solid tubulars and perforated tubulars within the wellbore;

radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;

20        fluidically coupling the perforated tubulars and the solid tubulars;

monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;

controlling the flow of fluidic materials through the perforated tubulars as a function of the monitored operating temperatures, pressures, and flow rates; and

25        preventing the passage of fluids from the first subterranean zone to the second subterranean zone within the wellbore external to the solid tubulars and perforated tubulars.

Preferably, the perforated tubulars that are radially expanded into intimate contact with the perforated casing compress the second subterranean zone.

30        Preferably, the method further comprises vibrating the second subterranean zone to increase the rate of recovery of hydrocarbons from the second subterranean zone.

Preferably, the method further comprises vibrating the second subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.

.....

Preferably, the method further comprises applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the second subterranean zone.

5       According to another aspect of the present invention, there is provided a method of extracting materials from a producing subterranean zone in a wellbore, at least a portion of the wellbore including a casing and a perforated casing that traverses the producing subterranean zone, comprising;

          positioning one or more solid tubulars within the wellbore;

10       positioning one or more perforated tubulars within the wellbore each including one or more radial passages, the perforated tubulars traversing the producing subterranean zone;

          radially expanding at least one of the solid tubulars and the perforated tubulars within the wellbore;

15       radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;

          fluidically coupling the solid tubulars with the casing;

          fluidically coupling the perforated tubulars with the solid tubulars;

20       fluidically isolating the producing subterranean zone from at least one other subterranean zone within the wellbore;

          monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;

          controlling the flow of fluidic materials through the perforated tubulars as a function of the monitored operating temperatures, pressures, and flow rates; and

25       fluidically coupling at least one of the perforated tubulars with the producing subterranean zone.

          Preferably, the perforated tubulars that are radially expanded into intimate contact with the perforated casing compress the producing subterranean zone.

30       Preferably, the method further comprises vibrating the producing subterranean zone to increase the rate of recovery of hydrocarbons from the producing subterranean zone.

          Preferably, the method further comprises vibrating the producing subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.

Preferably, the method further comprises applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the producing subterranean zone.

5        According to another aspect of the present invention, there is provided a system for isolating a first subterranean zone from a second subterranean zone in a wellbore that includes a perforated casing that traverses the second subterranean zone, comprising:

10        means for positioning one or more solid tubulars within the wellbore, the solid tubulars traversing the first subterranean zone;

      means for positioning one or more perforated tubulars within the wellbore each including one or more radial passages, the perforated tubulars traversing the second subterranean zone;

15        means for radially expanding at least one of the solid tubulars and perforated tubulars within the wellbore;

      means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;

      means for fluidically coupling the perforated tubulars and the solid tubulars;

20        means for monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;

      means for controlling the flow of fluidic materials through the perforated tubulars as a function of the monitored operating temperatures, pressures, and flow rates; and

25        means for preventing the passage of fluids from the first subterranean zone to the second subterranean zone within the wellbore external to the solid tubulars and perforated tubulars.

      Preferably, the means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing comprises

      means for compressing the second subterranean zone.

30        Preferably, the system further comprises means for vibrating the second subterranean zone to increase the rate of recovery of hydrocarbons from the second subterranean zone.

      Preferably, the system further comprises means for vibrating the second subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.



Preferably, the system further comprises means for applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the second subterranean zone.

5       According to another aspect of the present invention, there is provided a the system for extracting materials from a producing subterranean zone in a wellbore, at least a portion of the wellbore including a casing and a perforated casing that traverses the producing subterranean zone, comprising;

      means for positioning one or more solid tubulars within the wellbore;

10       means for positioning one or more perforated tubulars within the wellbore each including one or more radial openings, the perforated tubulars traversing the producing subterranean zone;

      means for radially expanding at least one of the solid tubulars and the perforated tubulars within the wellbore;

15       means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;

      means for fluidicly coupling the solid tubulars with the casing;

      means for fluidicly coupling the perforated tubulars with the solid tubulars;

      means for fluidicly isolating the producing subterranean zone from at least one  
20 other subterranean zone within the wellbore;

      means for monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;

      means for controlling the flow of fluidic materials through the perforated tubulars as a function of the monitored operating temperatures, pressures, and flow rates; and

25       means for fluidicly coupling at least one of the perforated tubulars with the producing subterranean zone.

      Preferably, the means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing comprises means for compressing the producing subterranean zone.

30       Preferably, the system further comprises means for vibrating the producing subterranean zone to increase the rate of recovery of hydrocarbons from the producing subterranean zone.

Preferably, the system further comprises means for vibrating the producing subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.

5 Preferably, the system further comprises means for applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the producing subterranean zone.

### **Brief Description of the Drawings**

10 In the accompanying drawings, Figure 12 illustrates an embodiment of the invention. The other drawings are included to provide background to the invention. More specifically:

FIG. 1 is a fragmentary cross-sectional view illustrating the isolation of subterranean zones.

15 Fig. 2a is a cross sectional illustration of the placement of a system for isolating subterranean zones within a borehole.

Fig. 2b is a cross sectional illustration of the system of Fig. 2a during the injection of a fluidic material into the tubular support member.

20 Fig. 2c is a cross sectional illustration of the system of Fig. 2b while pulling the tubular expansion cone out of the wellbore.

Fig. 2d is a cross sectional illustration of the system of Fig. 2c after the tubular expansion cone has been completely pulled out of the wellbore.

Fig. 3 is a cross sectional illustration of the expandable tubular members of the system of Fig. 2a.

25 Fig. 4 is a flow chart illustration of a method for manufacturing the expandable tubular member of Fig. 3.

Fig. 5a is a cross sectional illustration of the upsetting of the ends of a tubular member.

30 Fig. 5b is a cross sectional illustration of the expandable tubular member of Fig. 5a after radially expanding and plastically deforming the ends of the expandable tubular member.

Fig. 5c is a cross sectional illustration of the expandable tubular member of Fig. 5b after forming threaded connections on the ends of the expandable tubular member.

Fig. 5d is a cross sectional illustration of the expandable tubular member of Fig. 5c after coupling sealing members to the exterior surface of the intermediate unexpanded portion of the expandable tubular member.

Fig. 6 is a cross-sectional illustration of a tubular expansion cone.

5 Fig. 7 is a cross-sectional illustration of a tubular expansion cone.

Fig. 8 is a fragmentary cross sectional illustration of an alternative system for isolating subterranean zones of Fig. 1.

Fig. 9 is a fragmentary cross sectional illustration of a method for lining one of the perforated tubular members of the system for isolating subterranean zones of Fig. 1 with a solid tubular liner.

Fig. 10 is a fragmentary cross sectional illustration of a method for sealing one of the perforated tubular members of the system for isolating subterranean zones of Fig. 1 with a hardenable fluidic sealing material.

Fig. 11 is a fragmentary cross sectional illustration of a method for coupling one of the perforated tubular members of the system for isolating subterranean zones of Fig. 1 with the surrounding subterranean formation.

Fig. 12 is a fragmentary cross sectional illustration of a method, in accordance with the present invention, for coupling one of the perforated tubular members of the system for isolating subterranean zones of Fig. 1 with a surrounding perforated wellbore casing.

Fig. 13 is a fragmentary cross sectional illustration of a method for lining one of the perforated tubular members of the system for isolating subterranean zones of Fig. 1 with another perforated tubular member.

Fig. 14 is a fragmentary cross sectional illustration of an alternative system for isolating subterranean zones of Fig. 1 that includes a one-way valve for preventing flow from a producing zone into a depleted zone.

Fig. 15 is a fragmentary cross sectional illustration of an alternative system for isolating subterranean zones of Fig. 1 in which the system is used to extract geothermal energy from a subterranean geothermal zone.

#### 30 Detailed Description

An apparatus and method for isolating one or more subterranean zones from one or more other subterranean zones is provided. The apparatus and method permits a producing zone to be isolated from a nonproducing zone using a combination of solid and slotted tubulars. In the production mode, the teachings of the present disclosure

may be used in combination with conventional, well known, production completion equipment and methods using a series of packers, solid tubing, perforated tubing, and sliding sleeves, which will be inserted into the disclosed apparatus to permit the commingling and/or isolation of the subterranean zones from each other.

Referring to Fig. 1, a wellbore 105 including a casing 110 are positioned in a subterranean formation 115. The subterranean formation 115 includes a number of productive and non-productive zones, including a water zone 120 and a targeted oil sand zone 125. During exploration of the subterranean formation 115, the wellbore 105 may be extended in a well known manner to traverse the various productive and non-productive zones, including the water zone 120 and the targeted oil sand zone 125.

In order to fluidically isolate the water zone 120 from the targeted oil sand zone 125, an apparatus 130 is provided that includes one or more sections of solid casing 135, one or more external seals 140, one or more sections of perforated casing 145, one or more intermediate sections of solid casing 150, and a solid shoe 155. The perforated casing 145 includes one or more radial passages.

The solid casing 135 provides a fluid conduit that transmits fluids and other materials from one end of the solid casing 135 to the other end of the solid casing 135. The solid casing 135 may comprise any number of conventional commercially available sections of solid tubular casing such as, for example, oilfield tubulars fabricated from chromium steel or fiberglass. The solid casing 135 comprises oilfield tubulars available from various foreign and domestic steel mills.

The solid casing 135 is preferably coupled to the casing 110. The solid casing 135 may be coupled to the casing 110 using any number of conventional commercially available processes such as, for example, welding, slotted and expandable connectors, or expandable solid connectors. The solid casing 135 is coupled to the casing 110 by using expandable solid connectors. The solid casing 135 may comprise a plurality of such solid casing 135.

The solid casing 135 is preferably coupled to one more of the perforated casings 145. The solid casing 135 may be coupled to the perforated casing 145 using any number of conventional commercially available processes such as, for example, welding, or slotted and expandable connectors. The solid casing 135 is coupled to the perforated casing 145 by expandable solid connectors.

The solid casing 135 includes one more valve members 160 for controlling the flow of fluids and other materials within the interior region of the casing 135. During the production mode of operation, an internal tubular string with various arrangements of packers, perforated tubing, sliding sleeves, and valves may be employed within the

apparatus to provide various options for commingling and isolating subterranean zones from each other while providing a fluid path to the surface.

The casing 135 is placed into the wellbore 105 by expanding the casing 135 in the radial direction into intimate contact with the interior walls of the wellbore 105. The casing 135 may be expanded in the radial direction using any number of conventional commercially available methods.

The seals 140 prevent the passage of fluids and other materials within the annular region 165 between the solid casings 135 and 150 and the wellbore 105. The seals 140 may comprise any number of conventional commercially available sealing materials suitable for sealing a casing in a wellbore such as, for example, lead, rubber or epoxy. The seals 140 comprise Stratalok epoxy material available from Halliburton Energy Services. The perforated casing 145 permits fluids and other materials to pass into and out of the interior of the perforated casing 145 from and to the annular region 165. In this manner, oil and gas may be produced from a producing subterranean zone within a subterranean formation. The perforated casing 145 may comprise any number of conventional commercially available sections of slotted tubular casing. The perforated casing 145 comprises expandable slotted tubular casing available from Petrolite in Aberdeen, Scotland. The perforated casing 145 comprises expandable slotted sandscreen tubular casing available from Petrolite in Aberdeen, Scotland.

The perforated casing 145 is preferably coupled to one or more solid casing 135. The perforated casing 145 may be coupled to the solid casing 135 using any number of conventional commercially available processes such as, for example, welding, or slotted or solid expandable connectors. The perforated casing 145 is coupled to the solid casing 135 by expandable solid connectors.

The perforated casing 145 is preferably coupled to one or more intermediate solid casings 150. The perforated casing 145 may be coupled to the intermediate solid casing 150 using any number of conventional commercially available processes such as, for example, welding or expandable solid or slotted connectors. The perforated casing 145 is coupled to the intermediate solid casing 150 by expandable solid connectors.

The last perforated casing 145 is preferably coupled to the shoe 155. The last perforated casing 145 may be coupled to the shoe 155 using any number of conventional commercially available processes such as, for example, welding or

expandable solid or slotted connectors. The last perforated casing 145 is coupled to the shoe 155 by an expandable solid connector.

Instead, the shoe 155 may be coupled directly to the last one of the intermediate solid casings 150.

- 5        The perforated casings 145 are positioned within the wellbore 105 by expanding the perforated casings 145 in a radial direction into intimate contact with the interior walls of the wellbore 105. The perforated casings 145 may be expanded in a radial direction using any number of conventional commercially available processes.

- 10       The intermediate solid casing 150 permits fluids and other materials to pass between adjacent perforated casings 145. The intermediate solid casing 150 may comprise any number of conventional commercially available sections of solid tubular casing such as, for example, oilfield tubulars fabricated from chromium steel or fiberglass. The intermediate solid casing 150 comprises oilfield tubulars available from foreign and domestic steel mills.

- 15       The intermediate solid casing 150 is preferably coupled to one or more sections of the perforated casing 145. The intermediate solid casing 150 may be coupled to the perforated casing 145 using any number of conventional commercially available processes such as, for example, welding, or solid or slotted expandable connectors. The intermediate solid casing 150 is coupled to the perforated casing 145 by  
20       expandable solid connectors. The intermediate solid casing 150 may comprise a plurality of such intermediate solid casing 150.

- Each intermediate solid casing 150 includes one more valve members 170 for controlling the flow of fluids and other materials within the interior region of the intermediate casing 150. As will be recognized by persons having ordinary skill in the  
25       art and the benefit of the present disclosure, during the production mode of operation, an internal tubular string with various arrangements of packers, perforated tubing, sliding sleeves, and valves may be employed within the apparatus to provide various options for commingling and isolating subterranean zones from each other while providing a fluid path to the surface.

- 30       The intermediate casing 150 is placed into the wellbore 105 by expanding the intermediate casing 150 in the radial direction into intimate contact with the interior walls of the wellbore 105. The intermediate casing 150 may be expanded in the radial direction using any number of conventional commercially available methods.

One or more of the intermediate solid casings 150 may be omitted. Preferably, one or more of the perforated casings 145 are provided with one or more seals 140.

The shoe 155 provides a support member for the apparatus 130. In this manner, various production and exploration tools may be supported by the shoe 150. The shoe 150 may comprise any number of conventional commercially available shoes suitable for use in a wellbore such as, for example, cement filled shoe, or an aluminum or composite shoe. The shoe 150 comprises an aluminum shoe available from Halliburton. The shoe 155 is selected to provide sufficient strength in compression and tension to permit the use of high capacity production and exploration tools.

The apparatus 130 includes a plurality of solid casings 135, a plurality of seals 140, a plurality of perforated casings 145, a plurality of intermediate solid casings 150, and a shoe 155. More generally, the apparatus 130 may comprise one or more solid casings 135, each with one or more valve members 160,  $n$  perforated casings 145,  $n-1$  intermediate solid casings 150, each with one or more valve members 170, and a shoe 155.

During operation of the apparatus 130, oil and gas may be controllably produced from the targeted oil sand zone 125 using the perforated casings 145. The oil and gas may then be transported to a surface location using the solid casing 135. The use of intermediate solid casings 150 with valve members 170 permits isolated sections of the zone 125 to be selectively isolated for production. The seals 140 permit the zone 125 to be fluidically isolated from the zone 120. The seals 140 further permits isolated sections of the zone 125 to be fluidically isolated from each other. In this manner, the apparatus 130 permits unwanted and/or non-productive subterranean zones to be fluidically isolated.

As will be recognized by persons having ordinary skill in the art and also having the benefit of the present disclosure, during the production mode of operation, an internal tubular string with various arrangements of packers, perforated tubing, sliding sleeves, and valves may be employed within the apparatus to provide various options for commingling and isolating subterranean zones from each other while providing a fluid path to the surface.

The solid casing 135, the perforated casings 145, the intermediate sections of solid casing 150, and/or the solid shoe 155 may be radially expanded and plastically deformed within the wellbore 105 in a conventional manner and/or using one or more of the methods and apparatus disclosed in one or more of the following: (1) U.S. patent



application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999,  
 (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed  
 on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no.  
 25791.8.02, filed on 2/10/2000, (4) U.S. patent application serial no. 09/440,338,  
 5 attorney docket no. 25791.9.02, filed on 11/15/1999, (5) U.S. patent application serial  
 no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent  
 application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000,  
 (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed  
 on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no.  
 10 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, .....  
 attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial .....  
 no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. ....  
 provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed .....  
 on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney .....  
 15 docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial .....  
 no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. ....  
 provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed .....  
 on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney  
 docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial  
 20 no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional  
 patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on  
 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney  
 docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial  
 no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional  
 25 patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on  
 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney  
 docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial  
 no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001; (23) U.S. provisional  
 patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on  
 30 1/17/2001; (24) U.S. provisional patent application serial no. 60/259,486, attorney  
 docket no. 25791.52, filed on 1/3/2001; (25) U.S. provisional patent application serial  
 no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001; (26) U.S. provisional  
 patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on  
 8/20/2001; (27) U.S. provisional patent application serial no. 60/317,985, attorney

docket no. 25791.67, filed on 9/6/2001; (28) U.S. provisional patent application serial no. 60/318,386, attorney docket no. 25791.67.02, filed on 9/10/2001; and (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001. The radial clearances between the radially expanded solid casings 135, perforated casings 145, intermediate sections of solid casing 150, and/or the solid shoe 155 and the wellbore 105 may be eliminated thereby eliminating the annulus between the solid casings, the perforated casings 145, the intermediate sections of solid casing 150, and/or the solid shoe 155 and the wellbore 105. In this manner, the optional need for filling the annulus with a filler material such as, for example, gravel, may be eliminated.

Referring to Figs. 2a-2d, a system 200 for isolating subterranean formations includes a tubular support member 202 that defines a passage 202a. A tubular expansion cone 204 that defines a passage 204a is coupled to an end of the tubular support member 202. The tubular expansion cone 204 includes a tapered outer surface 204b for reasons to be described.

A pre-expanded end 206a of a first expandable tubular member 206 that defines a passage 206b is adapted to mate with and be supported by the tapered outer surface 204b of the tubular expansion cone 204. The first expandable tubular member 206 further includes an unexpanded intermediate portion 206c, another pre-expanded end 206d, and a sealing member 206e coupled to the exterior surface of the unexpanded intermediate portion. The inside and outside diameters of the pre-expanded ends, 206a and 206d, of the first expandable tubular member 206 are greater than the inside and outside diameters of the unexpanded intermediate portion 206c. An end 208a of a shoe 208 is coupled to the pre-expanded end 206a of the first expandable tubular member 206 by a conventional threaded connection.

An end 210a of a slotted tubular member 210 that defines a passage 210b is coupled to the other pre-expanded end 206d of the first expandable tubular member 206 by a conventional threaded connection. Another end 210c of the slotted tubular member 210 is coupled to an end 212a of a slotted tubular member 212 that defines a passage 212b by a conventional threaded connection. A pre-expanded end 214a of a second expandable tubular member 214 that defines a passage 214b is coupled to the other end 212c of the tubular member 212. The second expandable tubular member 214 further includes an unexpanded intermediate portion 214c, another pre-expanded end 214d, and a sealing member 214e coupled to the exterior surface of the unexpanded intermediate portion. The inside and outside diameters of the pre-expanded ends, 214a and 214d, of the second expandable tubular member 214 are greater than the inside and outside diameters of the unexpanded intermediate portion 214c.

An end 216a of a slotted tubular member 216 that defines a passage 216b is coupled to the other pre-expanded end 214d of the second expandable tubular member 214 by a conventional threaded connection. Another end 216c of the slotted tubular member 216 is coupled to an end 218a of a slotted tubular member 218 that defines a passage 218b by a conventional threaded connection. A pre-expanded end 220a of a third expandable tubular member 220 that defines a passage 220b is coupled to the other end 218c of the slotted tubular member 218. The third expandable tubular member 220 further includes an unexpanded intermediate portion 220c, another pre-expanded end 220d, and a sealing member 220e coupled to the exterior surface of the unexpanded intermediate portion. The inside and outside diameters of the pre-expanded ends, 220a and 220d, of the third expandable tubular member 220 are greater than the inside and outside diameters of the unexpanded intermediate portion 220c.

An end 222a of a tubular member 222 is threadably coupled to the end 30d of the third expandable tubular member 220.

The inside and outside diameters of the pre-expanded ends, 206a, 206d, 214a, 214d, 220a and 220d, of the expandable tubular members, 206, 214, and 220, and the slotted tubular members 210, 212, 216, and 218, may be substantially equal. The sealing members, 206e, 214e, and 220e, of the expandable tubular members, 206, 214, and 220, respectively, further include anchoring elements for engaging the wellbore casing 104. The slotted tubular members, 210, 212, 216, and 218, may be

conventional slotted tubular members having threaded end connections suitable for use in an oil or gas well, an underground pipeline, or as a structural support. The slotted tubular members, 210, 212, 216, and 218 may be conventional slotted tubular members for recovering or introducing fluidic materials such as, for example, oil, gas and/or water from or into a subterranean formation.

As illustrated in Fig. 2a, the system 200 is initially positioned in a borehole 224 formed in a subterranean formation 226 that includes a water zone 226a and a targeted oil sand zone 226b. The borehole 224 may be positioned in any orientation from vertical to horizontal. The upper end of the tubular support member 202 may be supported in a conventional manner using, for example, a slip joint, or equivalent device in order to permit upward movement of the tubular support member and tubular expansion cone 204 relative to one or more of the expandable tubular members, 206, 214, and 220, and tubular members, 210, 212, 216, and 218.

As illustrated in Fig. 2b, a fluidic material 228 is then injected into the system 200 through the passages, 202a and 204a, of the tubular support member 202 and tubular expansion cone 204, respectively.

As illustrated in Fig. 2c, the continued injection of the fluidic material 228 through the passages, 202a and 204a, of the tubular support member 202 and the tubular expansion cone 204, respectively, pressurizes the passage 18b of the shoe 18 below the tubular expansion cone thereby radially expanding and plastically deforming the expandable tubular member 206 off of the tapered external surface 204b of the tubular expansion cone 204. In particular, the intermediate non pre-expanded portion 206c of the expandable tubular member 206 is radially expanded and plastically deformed off of the tapered external surface 204b of the tubular expansion cone 204. As a result, the sealing member 206e engages the interior surface of the wellbore casing 104. Consequently, the radially expanded intermediate portion 206c of the expandable tubular member 206 is thereby coupled to the wellbore casing 104. The radially expanded intermediate portion 206c of the expandable tubular member 206 is also thereby anchored to the wellbore casing 104.

As illustrated in Fig. 2d, after the expandable tubular member 206 has been plastically deformed and radially expanded off of the tapered external surface 204b of the tubular expansion cone 204, the tubular expansion cone is pulled out of the borehole 224 by applying an upward force to the tubular support member 202. As a result, the second and third expandable tubular members, 214 and 220, are radially

expanded and plastically deformed off of the tapered external surface 204b of the  
 tubular expansion cone 204. In particular, the intermediate non pre-expanded portion  
 214c of the second expandable tubular member 214 is radially expanded and  
 plastically deformed off of the tapered external surface 204b of the tubular expansion  
 cone 204. As a result, the sealing member 214e engages the interior surface of the  
 wellbore 224. Consequently, the radially expanded intermediate portion 214c of the  
 5 second expandable tubular member 214 is thereby coupled to the wellbore 224. The  
 radially expanded intermediate portion 214c of the second expandable tubular member  
 214 is also thereby anchored to the wellbore 104. Furthermore, the continued  
 10 application of the upward force to the tubular member 202 will then displace the  
 tubular expansion cone 204 upwardly into engagement with the pre-expanded end  
 220a of the third expandable tubular member 220. Finally, the continued application of  
 the upward force to the tubular member 202 will then radially expand and plastically  
 deform the third expandable tubular member 220 off of the tapered external surface  
 15 204b of the tubular expansion cone 204. In particular, the intermediate non pre-  
 expanded portion 220c of the third expandable tubular member 220 is radially  
 expanded and plastically deformed off of the tapered external surface 204b of the  
 tubular expansion cone 204. As a result, the sealing member 220e engages the  
 interior surface of the wellbore 224. Consequently, the radially expanded intermediate  
 20 portion 220c of the third expandable tubular member 220 is thereby coupled to the  
 wellbore 224. The radially expanded intermediate portion 220c of the third expandable  
 tubular member 220 is also thereby anchored to the wellbore 224. As a result, the  
 water zone 226a and fluidly isolated from the targeted oil sand zone 226b.

After completing the radial expansion and plastic deformation of the third  
 25 expandable tubular member 220, the tubular support member 202 and the tubular  
 expansion cone 204 are removed from the wellbore 224.

Thus, during the operation of the system 10, the intermediate non pre-expanded  
 portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and  
 220, respectively, are radially expanded and plastically deformed by the upward  
 30 displacement of the tubular expansion cone 204. As a result, the sealing members,  
 206e, 214e, and 220e, are displaced in the radial direction into engagement with the  
 wellbore 224 thereby coupling the shoe 208, the expandable tubular member 206, the  
 slotted tubular members, 210 and 212, the expandable tubular member 214, the slotted  
 tubular members, 216 and 218, and the expandable tubular member 220 to the

wellbore. Furthermore, as a result, the connections between the expandable tubular members, 206, 214, and 220, the shoe 208, and the slotted tubular members, 210, 212, 216, and 218, do not have to be expandable connections thereby providing significant cost savings. In addition, the inside diameters of the expandable tubular members, 206, 214, and 220, and the slotted tubular members, 210, 212, 216, and 218, after the radial expansion process, are substantially equal. In this manner, additional conventional tools and other conventional equipment may be easily positioned within, and moved through, the expandable and slotted tubular members. The conventional tools and equipment include conventional valving and other conventional flow control devices for controlling the flow of fluidic materials within and between the expandable tubular members, 206, 214, and 220, and the slotted tubular members, 210, 212, 216, and 218.

Furthermore, in the system 200, the slotted tubular members 210, 212, 216, and 218 are interleaved among the expandable tubular members, 206, 214, and 220. As a result, because only the intermediate non pre-expanded portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and 220, respectively, are radially expanded and plastically deformed, the slotted tubular members, 210, 212, 216, and 218 can be conventional slotted tubular members thereby significantly reducing the cost and complexity of the system 10. Moreover, because only the intermediate non pre-expanded portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and 220, respectively, are radially expanded and plastically deformed, the number and length of the interleaved slotted tubular members, 210, 212, 216, and 218 can be much greater than the number and length of the expandable tubular members. The total length of the intermediate non pre-expanded portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and 220, is approximately 61 m (200 feet), and the total length of the slotted tubular members, 210, 212, 216, and 218, is approximately 1158 m (3800 feet). Consequently, A system 200 having a total length of approximately 1219 m (4000 feet) is coupled to the wellbore 224 by radially expanding and plastically deforming a total length of only approximately 61 m (200 feet).

Furthermore, the sealing members 206e, 214e, and 220e, of the expandable tubular members, 206, 214, and 220, respectively, are used to couple the expandable tubular members and the slotted tubular members, 210, 212, 216, and 218 to the wellbore 224, the radial gap between the slotted tubular members, the expandable

tubular members, and the wellbore 224 may be large enough to effectively eliminate the possibility of damage to the expandable tubular members and slotted tubular members during the placement of the system 200 within the wellbore.

5 The pre-expanded ends, 206a, 206d, 214a, 214d, 220a, and 220d, of the expandable tubular members, 206, 214, and 220, respectively, and the slotted tubular members, 210, 212, 216, and 218, have outside diameters and wall thicknesses of 213 mm (8.375 inches) and 8.89 mm (0.350 inches), respectively; prior to the radial expansion, the intermediate non pre-expanded portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and 220, respectively, have outside diameters  
10 of 194 mm (7.625 inches); the slotted tubular members, 210, 212, 216, and 218, have inside diameters of 195 mm (7.675 inches); after the radial expansion, the inside diameters of the intermediate portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and 220, are equal to 195 mm (7.675 inches); and the wellbore 224 has an inside diameter of 222 mm (8.755 inches).

15 The pre-expanded ends, 206a, 206d, 214a, 214d, 220a, and 220d, of the expandable tubular members, 206, 214, and 220, respectively, and the slotted tubular members, 210, 212, 216, and 218, have outside diameters and wall thicknesses of 114 mm (4.500 inches) and 6.35 mm (0.250 inches), respectively; prior to the radial expansion, the intermediate non pre-expanded portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and 220, respectively, have outside diameters  
20 of 102 mm (4.000 inches); the slotted tubular members, 210, 212, 216, and 218, have inside diameters of 102 mm (4.000 inches); after the radial expansion, the inside diameters of the intermediate portions, 206c, 214c, and 220c, of the expandable tubular members, 206, 214, and 220, are equal to 102 mm (4.000 inches); and the  
25 wellbore 224 has an inside diameter of 124 mm (4.892 inches).

The system 200 is used to inject or extract fluidic materials such as, for example, oil, gas, and/or water into or from the subterranean formation 226b.

Referring now to Fig. 3, another expandable tubular member 300 will now be described. The tubular member 300 defines an interior region 300a and includes a first  
30 end 300b including a first threaded connection 300ba, a first tapered portion 300c, an intermediate portion 300d, a second tapered portion 300e, and a second end 300f including a second threaded connection 300fa. The tubular member 300 further preferably includes an intermediate sealing member 300g that is coupled to the exterior surface of the intermediate portion 300d.

The tubular member 300 has a substantially annular cross section. The tubular member 300 may be fabricated from any number of conventional commercially available materials such as, for example, Oilfield Country Tubular Goods (OCTG), 13 chromium steel tubing/casing, or L83, J55, or P110 API casing.

5        The interior 300a of the tubular member 300 has a substantially circular cross section. Furthermore, The interior region 300a of the tubular member includes a first inside diameter  $D_1$ , an intermediate inside diameter  $D_{INT}$ , and a second inside diameter  $D_2$ . The first and second inside diameters,  $D_1$  and  $D_2$ , are substantially equal. The first and second inside diameters,  $D_1$  and  $D_2$ , are greater than the intermediate inside  
10        diameter  $D_{INT}$ .

      The first end 300b of the tubular member 300 is coupled to the intermediate  
portion 300d by the first tapered portion 300c, and the second end 300f of the tubular  
member is coupled to the intermediate portion by the second tapered portion 300e.  
The outside diameters of the first and second ends, 300b and 300f, of the tubular  
15        member 300 is greater than the outside diameter of the intermediate portion 300d of  
the tubular member. The first and second ends, 300b and 300f, of the tubular member  
300 include wall thicknesses,  $t_1$  and  $t_2$ , respectively. The outside diameter of the  
intermediate portion 300d of the tubular member 300 ranges from about 75% to 98% of  
the outside diameters of the first and second ends, 300a and 300f. The intermediate  
20        portion 300d of the tubular member 300 includes a wall thickness  $t_{INT}$ .

      The wall thicknesses  $t_1$  and  $t_2$  are substantially equal in order to provide  
substantially equal burst strength for the first and second ends, 300a and 300f, of the  
tubular member 300. The wall thicknesses,  $t_1$  and  $t_2$ , are both greater than the wall  
thickness  $t_{INT}$  in order to optimally match the burst strength of the first and second  
25        ends, 300a and 300f, of the tubular member 300 with the intermediate portion 300d of  
the tubular member 300.

      The first and second tapered portions, 300c and 300e, may be inclined at an  
angle,  $\alpha$ , relative to the longitudinal direction ranging from about 0 to 30 degrees in  
order to optimally facilitate the radial expansion of the tubular member 300. The first  
30        and second tapered portions, 300c and 300e, provide a smooth transition between the  
first and second ends, 300a and 300f, and the intermediate portion 300d, of the tubular  
member 300 in order to minimize stress concentrations.

      The intermediate sealing member 300g is coupled to the outer surface of the  
intermediate portion 300d of the tubular member 300. The intermediate sealing



member 300g seals the interface between the intermediate portion 300d of the tubular member 300 and the interior surface of a wellbore casing 305, or other preexisting structure, after the radial expansion and plastic deformation of the intermediate portion 300d of the tubular member 300. The intermediate sealing member 300g has a substantially annular cross section. The outside diameter of the intermediate sealing member 300g is selected to be less than the outside diameters of the first and second ends, 300a and 300f, of the tubular member 300 in order to optimally protect the intermediate sealing member 300g during placement of the tubular member 300 within the wellbore casings 305. The intermediate sealing member 300g may be fabricated from any number of conventional commercially available materials such as, for example, thermoset or thermoplastic polymers. The intermediate sealing member 300g is fabricated from thermoset polymers in order to optimally seal the radially expanded intermediate portion 300d of the tubular member 300 with the wellbore casing 305. The sealing member 300g may include one or more rigid anchors for engaging the wellbore casing 305 to thereby anchor the radially expanded and plastically deformed intermediate portion 300d of the tubular member 300 to the wellbore casing.

Referring to Figs. 4, and 5a to 5d, The tubular member 300 is formed by a process 400 that includes the steps of: (1) upsetting both ends of a tubular member in step 405; (2) expanding both upset ends of the tubular member in step 410; (3) stress relieving both expanded upset ends of the tubular member in step 415; (4) forming threaded connections in both expanded upset ends of the tubular member in step 420; and (5) putting a sealing material on the outside diameter of the non-expanded intermediate portion of the tubular member in step 425.

As illustrated in FIG. 5a, in step 405, both ends, 500a and 500b, of a tubular member 500 are upset using conventional upsetting methods. The upset ends, 500a and 500b, of the tubular member 500 include the wall thicknesses  $t_1$  and  $t_2$ . The intermediate portion 500c of the tubular member 500 includes the wall thickness  $t_{INT}$  and the interior diameter  $D_{INT}$ . The wall thicknesses  $t_1$  and  $t_2$  are substantially equal in order to provide burst strength that is substantially equal along the entire length of the tubular member 500. The wall thicknesses  $t_1$  and  $t_2$  are both greater than the wall thickness  $t_{INT}$  in order to provide burst strength that is substantially equal along the entire length of the tubular member 500, and also to optimally facilitate the formation of threaded connections in the first and second ends, 500a and 500b.

As illustrated in Fig. 5b, in steps 410 and 415, both ends, 500a and 500b, of the tubular member 500 are radially expanded using conventional radial expansion methods, and then both ends, 500a and 500b, of the tubular member are stress relieved. The radially expanded ends, 500a and 500b, of the tubular member 500 include the interior diameters  $D_1$  and  $D_2$ . The interior diameters  $D_1$  and  $D_2$  are substantially equal in order to provide a burst strength that is substantially equal. The ratio of the interior diameters  $D_1$  and  $D_2$  to the interior diameter  $D_{INT}$  ranges from about 100% to 120% in order to facilitate the subsequent radial expansion of the tubular member 500.

The relationship between the wall thicknesses  $t_1$ ,  $t_2$ , and  $t_{INT}$  of the tubular member 500; the inside diameters  $D_1$ ,  $D_2$  and  $D_{INT}$  of the tubular member 500; the inside diameter  $D_{wellbore}$  of the wellbore casing, or other structure, that the tubular member 500 will be inserted into; and the outside diameter  $D_{cone}$  of the expansion cone that will be used to radially expand the tubular member 500 within the wellbore casing is given by the following expression:

$$D_{wellbore} - 2 * t_1 \geq \frac{1}{t_1} [(t_1 - t_{INT}) * D_{cone} + t_{INT} * D_{INT}]$$

where  $t_1 = t_2$ ; and

$$D_1 = D_2.$$

By satisfying the relationship given in equation (1), the expansion forces placed upon the tubular member 500 during the subsequent radial expansion process are substantially equalized. More generally, the relationship given in equation (1) may be used to calculate the optimal geometry for the tubular member 500 for subsequent radial expansion and plastic deformation of the tubular member 500 for fabricating and/or repairing a wellbore casing, a pipeline, or a structural support.

As illustrated in FIG. 5c, in step 420, conventional threaded connections, 500d and 500e, are formed in both expanded ends, 500a and 500b, of the tubular member 500. The threaded connections, 500d and 500e, are provided using conventional processes for forming pin and box type threaded connections available from Atlas-Bradford.

As illustrated in Fig. 5d, in step 425, a sealing member 500f is then applied onto the outside diameter of the non-expanded intermediate portion 500c of the tubular member 500. The sealing member 500f may be applied to the outside diameter of the non-expanded intermediate portion 500c of the tubular member 500 using any number

of conventional commercially available methods. The sealing member 500f is applied to the outside diameter of the intermediate portion 500c of the tubular member 500 using commercially available chemical and temperature resistant adhesive bonding.

5 The expandable tubular members, 206, 214, and 220, of the system 200 may be substantially identical to, and/or incorporate one or more of the teachings of, the tubular members 300 and 500.

Referring to Fig. 6, a tubular expansion cone 600 for radially expanding the tubular members 206, 214, 220, 300 and 500 will now be described. The expansion cone 600 defines a passage 600a and includes a front end 605, a rear end 610, and a  
10 radial expansion section 615.

The radial expansion section 615 includes a first conical outer surface 620 and a  
second conical outer surface 625. The first conical outer surface 620 includes an angle  
of attack  $\alpha_1$  and the second conical outer surface 625 includes an angle of attack  $\alpha_2$ .  
The angle of attack  $\alpha_1$  is greater than the angle of attack  $\alpha_2$ . In this manner, the first  
15 conical outer surface 620 optimally radially expands the intermediate portions, 206c,  
214c, 220c, 300d, and 500c, of the tubular members, 206, 214, 220, 300, and 500, and  
the second conical outer surface 525 optimally radially expands the pre-expanded first  
and second ends, 206a and 206d, 214a and 214d, 220a and 220d, 300b and 300f, and  
500a and 500b, of the tubular members, 206, 214, 220, 300 and 500. The first conical  
20 outer surface 620 includes an angle of attack  $\alpha_1$  ranging from about 8 to 20 degrees,  
and the second conical outer surface 625 includes an angle of attack  $\alpha_2$  ranging from  
about 4 to 15 degrees in order to optimally radially expand and plastically deform the  
tubular members, 206, 214, 220, 300 and 500. More generally, the expansion cone  
600 may include 3 or more adjacent conical outer surfaces having angles of attack that  
25 decrease from the front end 605 of the expansion cone 600 to the rear end 610 of the  
expansion cone 600.

Referring to Fig. 7, another tubular expansion cone 700 defines a passage 700a and includes a front end 705, a rear end 710, and a radial expansion section 715. The radial expansion section 715 includes an outer surface having a substantially parabolic  
30 outer profile thereby providing a paraboloid shape. In this manner, the outer surface of  
the radial expansion section 715 provides an angle of attack that constantly decreases  
from a maximum at the front end 705 of the expansion cone 700 to a minimum at the  
rear end 710 of the expansion cone. The parabolic outer profile of the outer surface of  
the radial expansion section 715 may be formed using a plurality of adjacent discrete

conical sections and/or using a continuous curved surface. In this manner, the region of the outer surface of the radial expansion section 715 adjacent to the front end 705 of the expansion cone 700 may optimally radially expand the intermediate portions, 206c, 214c, 220c, 300d, and 500c, of the tubular members, 206, 214, 220, 300, and 500, while the region of the outer surface of the radial expansion section 715 adjacent to the rear end 710 of the expansion cone 700 may optimally radially expand the pre-expanded first and second ends, 206a and 206d, 214a and 214d, 220a and 220d, 300b and 300f, and 500a and 500b, of the tubular members, 206, 214, 220, 300 and 500. The parabolic profile of the outer surface of the radial expansion section 715 is selected to provide an angle of attack that ranges from about 8 to 20 degrees in the vicinity of the front end 705 of the expansion cone 700 and an angle of attack in the vicinity of the rear end 710 of the expansion cone 700 from about 4 to 15 degrees.

The tubular expansion cone 204 of the system 200 is substantially identical to the expansion cones 600 or 700, and/or incorporates one or more of the teachings of the expansion cones 600 and/or 700.

The teachings of the apparatus 130, the system 200, the expandable tubular member 300, the method 400, and/or the expandable tubular member 500 may be at least partially combined.

Referring to Fig. 8, conventional temperature, pressure, and flow sensors, 802, 804, and 806, respectively, are operably coupled to the perforated tubulars 145 of the apparatus 130. The temperature, pressure, and flow sensors, 802, 804, and 806, respectively, in turn are operably coupled to a controller 810 that receives and processes the output signals generated by the temperature, pressure, and flow sensors to thereby control the operation of the flow control valves 160 to enhance the operational efficiency of the apparatus 130. The control algorithms utilized by the controller 810 for controlling the operation of the flow control valves 160 as a function of the operating temperature, pressure, and flow rates within the perforated tubular members 145 are conventional.

Referring to Fig. 9, a solid tubular member 905 is coupled to one of the perforated tubular members 145 by radially expanding and plastically deforming the solid tubular member into engagement with the perforated tubular member in a conventional manner and/or using one or more of the radial expansion methods disclosed in one or more of the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent

application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000,  
 (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed  
 on 2/10/2000, (4) U.S. patent application serial no. 09/440,338, attorney docket no.  
 25791.9.02, filed on 11/15/1999, (5) U.S. patent application serial no. 09/523,460,  
 5 attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial  
 no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent  
 application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000,  
 (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed  
 on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no.  
 10 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no.  
 PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. ....  
 provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed . . .  
 on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney  
 docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial . . .  
 15 no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. ....  
 provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed  
 on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney . . . .  
 docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial . . . .  
 no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional  
 20 patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on  
 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney  
 docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial  
 no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional  
 patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on  
 25 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney  
 docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial  
 no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001; (23) U.S. provisional  
 patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on  
 1/17/2001; (24) U.S. provisional patent application serial no. 60/259,486, attorney  
 30 docket no. 25791.52, filed on 1/3/2001; (25) U.S. provisional patent application serial  
 no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001; (26) U.S. provisional  
 patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on  
 8/20/2001; (27) U.S. provisional patent application serial no. 60/317,985, attorney  
 docket no. 25791.67, filed on 9/6/2001; (28) U.S. provisional patent application serial

no. 60,318,386, attorney docket no. 25791.67.02, filed on 9/10/2001; and (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001. In this manner, the solid tubular member 905 fluidly seals the radial passages formed in the perforated tubular member 145 thereby preventing the  
5 passage of fluidic materials and/or formation materials through the perforated tubular member.

Referring to Fig. 10, the radial openings in one of the perforated tubular members 145 are sealed by injecting a hardenable fluidic sealing material 1005 into the radial openings in the one perforated tubular member by positioning a closed ended pipe  
10 1010 having one or more radial openings 1010a within the one perforated tubular member 145. Conventional sealing members 1015 and 1020 then seal the interface between the pipe 1010 and the opposite ends of the one perforated tubular member 145. The hardenable fluidic sealing material 1005 is then injected into the radial  
15 openings in the one perforated tubular member 145. The sealing members 140 prevent the passage of the hardenable fluidic sealing material out of the annulus between the one perforated tubular member 145 and the formation 125. The pipe 1010 and sealing members, 1015 and 1020, are then removed from the apparatus 130, and the hardenable fluidic sealing material is allowed to cure. A conventional drill  
20 string may then be used to remove any excess cured sealing material from the interior surface of the one perforated tubular member 145. The hardenable fluidic sealing material is a curable epoxy resin.

As illustrated in Fig. 11, one or more of the perforated tubular members 145 of the apparatus 130 may be radially expanded and plastically deformed into contact with the surrounding formation 125 thereby compressing the surrounding formation. In this  
25 manner, the surrounding formation 125 is maintained in a state of compression thereby stabilizing the surrounding formation, reducing the flow of loose particles from the surrounding formation into the radial openings of the perforated tubular member 145, and enhancing the recovery of hydrocarbons from the surrounding formation.

A seismic source 1105 is positioned on a surface location to thereby impart  
30 seismic energy into the formation 125. In this manner, particles lodged in the radial openings in the perforated tubular member 145 may be dislodged from the radial openings thereby enhancing the subsequent recovery of hydrocarbons from the formation 125.

After the perforated tubular member 145 has been radially expanded and plastically formed into contact with the surrounding formation 125, thereby coupling the perforated tubular member 145 to the surrounding formation, an impulsive load is applied to the perforated tubular member. The impulsive load may be applied to the  
5 perforated tubular member 145 by applying the load to the end of the apparatus 130. The impulsive load is then transferred to the surrounding formation 125 thereby compacting and/or slurrifying the surrounding formation. As a result, the recovery of hydrocarbons from the formation 125 is enhanced.

As illustrated in Fig. 12, a wellbore casing 1205 having one or more perforations  
10 1210 may be positioned within the wellbore 105 that traverses the formation 125. When the apparatus 130 is positioned within the wellbore 105, one or more of the  
perforated tubular members 145 of the apparatus 130 are radially expanded and  
plastically deformed into contact with the wellbore casing 1205 thereby compressing  
the surrounding formation 125. In this manner, the surrounding formation 125 is  
15 maintained in a state of compression thereby stabilizing the surrounding formation,  
reducing the flow of loose particles from the surrounding formation into the radial  
openings of the perforated tubular member 145, and enhancing the recovery of  
hydrocarbons from the surrounding formation.

A seismic source 1215 is positioned on a surface location to thereby impart  
20 seismic energy into the formation 125. In this manner, particles lodged in the radial  
openings in the perforated tubular member 145 may be dislodged from the radial  
openings thereby enhancing the subsequent recovery of hydrocarbons from the  
formation 125.

After the perforated tubular member 145 has been radially expanded and  
25 plastically formed into contact with the wellbore casing 1205, thereby coupling the  
perforated tubular member 145 to the surrounding formation, an impulsive load is  
applied to the perforated tubular member. The impulsive load may be applied to the  
perforated tubular member 145 by applying the load to the end of the apparatus 130.  
The impulsive load is then transferred to the surrounding formation 125 thereby  
30 compacting and/or slurrifying the surrounding formation. As a result, the recovery of  
hydrocarbons from the formation 125 is enhanced.

Referring to Fig. 13, one or more perforated tubular members 1305 are coupled  
to one of the perforated tubular members 145 by radially expanding and plastically  
deforming the perforated tubular member into engagement with the perforated tubular

member in a conventional manner and/or using one or more of the radial expansion methods disclosed in one or more of the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, 5 (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent application serial no. 09/440,338, attorney docket no. 25791.9.02, filed on 11/15/1999, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent 10 application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. 15 provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed 20 on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney 25 docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial 30 no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001; (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001; (24) U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001; (25) U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001; (26) U.S. provisional



patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001; (27) U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001; (28) U.S. provisional patent application serial no. 60/318,386, attorney docket no. 25791.67.02, filed on 9/10/2001; and (29) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001. In this manner, the perforated tubular member 905 modifies the flow characteristics of the perforated tubular member 145 thereby permitting the operator of the apparatus 130 to modify the overall flow characteristics of the apparatus.

As illustrated in Fig. 14, a one-way valve 1405 such as, for example, a check valve fluidically couples the interior of a pair of adjacent perforated tubular members, 145a and 145b, that extract hydrocarbons from corresponding subterranean zones A and B. In this manner, if zone B becomes depleted, hydrocarbons that are being extracted from zone A will not flow into the depleted zone B.

As illustrated in Fig. 15, the apparatus 130 is used to extract geothermal energy from a targeted subterranean geothermal zone 1505. In this manner, the operational efficiency of the extraction of geothermal energy is significantly enhanced due to the increased internal diameters of the various radially expanded elements of the apparatus 130 that permit greater volumetric flows.

The perforated tubular members, 145, 210, 212, 216, 218, and 1305 of the apparatus 130 may be cleaned by further radial expansion of the perforated tubular members. The amount of further radial expansion required to clean the radial passages of the perforated tubular members 145, 210, 212, 216, 218, and 1305 of the apparatus 130 ranged from about 1% to 2%.

Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. Accordingly, it is appropriate that the appended claims be construed broadly.

## **CLAIMS**

1. An apparatus, comprising:
  - a zonal isolation assembly positioned within a wellbore that traverses a
  - 5 subterranean formation and includes a perforated wellbore casing, comprising:
    - one or more solid tubular members, each solid tubular member including one or more external seals;
    - one or more perforated tubular members coupled to the solid tubular members;
    - one or more flow control valves operably coupled to the perforated tubular
    - 10 members for controlling the flow of fluidic materials through the perforated tubular members;
    - one or more temperature sensors located within a longitudinal flow passage of one or more of the perforated tubular members for monitoring the operating temperature within the perforated tubular members;
    - 15 one or more pressure sensors located within the longitudinal flow passage of one or more of the perforated tubular members for monitoring the operating pressure within the perforated tubular members;
    - one or more flow sensors located within the longitudinal flow passage of one or more of the perforated tubular members for monitoring the operating flow rate within
    - 20 the perforated tubular members;
    - a controller operably coupled to the flow control valves, the temperature sensors, the pressure sensors, and the flow sensors for monitoring the temperature, pressure and flow sensors and controlling the operation of the flow control valves; and
    - a shoe coupled to the zonal isolation assembly;
    - 25 wherein at least one of the solid tubular members and the perforated tubular members are formed by a radial expansion process performed within the wellbore; and
    - wherein at least one of the perforated tubular members are radially expanded into intimate contact with the perforated wellbore casing.
2. The apparatus of claim 1, wherein the perforated tubular members that are
- 30 radially expanded into intimate contact with the perforated casing compress the subterranean formation.
3. A method of isolating a first subterranean zone from a second subterranean zone in a wellbore that includes a perforated casing that traverses the second subterranean zone, comprising:

positioning one or more solid tubulars within the wellbore, the solid tubulars traversing the first subterranean zone;

positioning one or more perforated tubulars within the wellbore each including one or more radial passages, the perforated tubulars traversing the second

5 subterranean zone;

radially expanding at least one of the solid tubulars and perforated tubulars within the wellbore;

radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;

10 fluidically coupling the perforated tubulars and the solid tubulars;

monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;

controlling the flow of fluidic materials through the perforated tubulars as a function of the monitored operating temperatures, pressures, and flow rates; and

15 preventing the passage of fluids from the first subterranean zone to the second subterranean zone within the wellbore external to the solid tubulars and perforated tubulars.

4. The method of claim 3, wherein the perforated tubulars that are radially expanded into intimate contact with the perforated casing compress the second  
20 subterranean zone.

5. The method of claim 3, further comprising vibrating the second subterranean zone to increase the rate of recovery of hydrocarbons from the second subterranean  
25 zone.

6. The method of claim 3, further comprising vibrating the second subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.

30 7. The method of claim 3, further comprising applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the second subterranean zone.

8. A method of extracting materials from a producing subterranean zone in a wellbore, at least a portion of the wellbore including a casing and a perforated casing that traverses the producing subterranean zone, comprising;
- 5       positioning one or more solid tubulars within the wellbore;  
          positioning one or more perforated tubulars within the wellbore each including one or more radial passages, the perforated tubulars traversing the producing subterranean zone;  
          radially expanding at least one of the solid tubulars and the perforated tubulars  
10       within the wellbore;  
          radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;  
          fluidically coupling the solid tubulars with the casing;  
          fluidically coupling the perforated tubulars with the solid tubulars;  
15       fluidically isolating the producing subterranean zone from at least one other subterranean zone within the wellbore;  
          monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;  
          controlling the flow of fluidic materials through the perforated tubulars as a  
20       function of the monitored operating temperatures, pressures, and flow rates; and  
          fluidically coupling at least one of the perforated tubulars with the producing subterranean zone.
9. The method of claim 8, wherein the perforated tubulars that are radially  
25       expanded into intimate contact with the perforated casing compress the producing subterranean zone.
10. The method of claim 8, further comprising vibrating the producing subterranean  
30       zone to increase the rate of recovery of hydrocarbons from the producing subterranean zone.
11. The method of claim 8, further comprising vibrating the producing subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.

12. The method of claim 8, further comprising applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the producing  
5 subterranean zone.
13. A system for isolating a first subterranean zone from a second subterranean zone in a wellbore that includes a perforated casing that traverses the second subterranean zone, comprising:
- 10 means for positioning one or more solid tubulars within the wellbore, the solid tubulars traversing the first subterranean zone;
- means for positioning one or more perforated tubulars within the wellbore each including one or more radial passages, the perforated tubulars traversing the second subterranean zone;
- 15 means for radially expanding at least one of the solid tubulars and perforated tubulars within the wellbore;
- means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;
- means for fluidically coupling the perforated tubulars and the solid tubulars;
- 20 means for monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;
- means for controlling the flow of fluidic materials through the perforated tubulars as a function of the monitored operating temperatures, pressures, and flow rates; and
- 25 means for preventing the passage of fluids from the first subterranean zone to the second subterranean zone within the wellbore external to the solid tubulars and perforated tubulars.
14. The system of claim 13, wherein the means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing comprises  
30 means for compressing the second subterranean zone.
15. The system of claim 13, further comprising means for vibrating the second subterranean zone to increase the rate of recovery of hydrocarbons from the second subterranean zone.

16. The system of claim 13, further comprising means for vibrating the second subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.

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17. The system of claim 13, further comprising means for applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the second subterranean zone.

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18. A system for extracting materials from a producing subterranean zone in a wellbore, at least a portion of the wellbore including a casing and a perforated casing that traverses the producing subterranean zone, comprising;

means for positioning one or more solid tubulars within the wellbore;

15 means for positioning one or more perforated tubulars within the wellbore each including one or more radial openings, the perforated tubulars traversing the producing subterranean zone;

means for radially expanding at least one of the solid tubulars and the perforated tubulars within the wellbore;

20 means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing;

means for fluidicly coupling the solid tubulars with the casing;

means for fluidicly coupling the perforated tubulars with the solid tubulars;

25 means for fluidicly isolating the producing subterranean zone from at least one other subterranean zone within the wellbore;

means for monitoring the operating temperatures, pressures, and flow rates within a longitudinal flow passage of one or more of the perforated tubulars;

means for controlling the flow of fluidic materials through the perforated tubulars as a function of the monitored operating temperatures, pressures, and flow rates; and

30 means for fluidicly coupling at least one of the perforated tubulars with the producing subterranean zone.

19. The system of claim 18, wherein the means for radially expanding at least one of the perforated tubulars into intimate contact with the perforated casing comprises means for compressing the producing subterranean zone.

5 20. The system of claim 18, further comprising means for vibrating the producing subterranean zone to increase the rate of recovery of hydrocarbons from the producing subterranean zone.

10 21. The system of claim 18, further comprising means for vibrating the producing subterranean zone to clean the radial passages of the perforated tubulars that are radially expanded into intimate contact with the perforated casing.

15 22. The system of claim 18, further comprising means for applying an impulsive load to the perforated tubulars that are radially expanded into intimate contact with the perforated casing to increase the rate of recovery of hydrocarbons from the producing subterranean zone.